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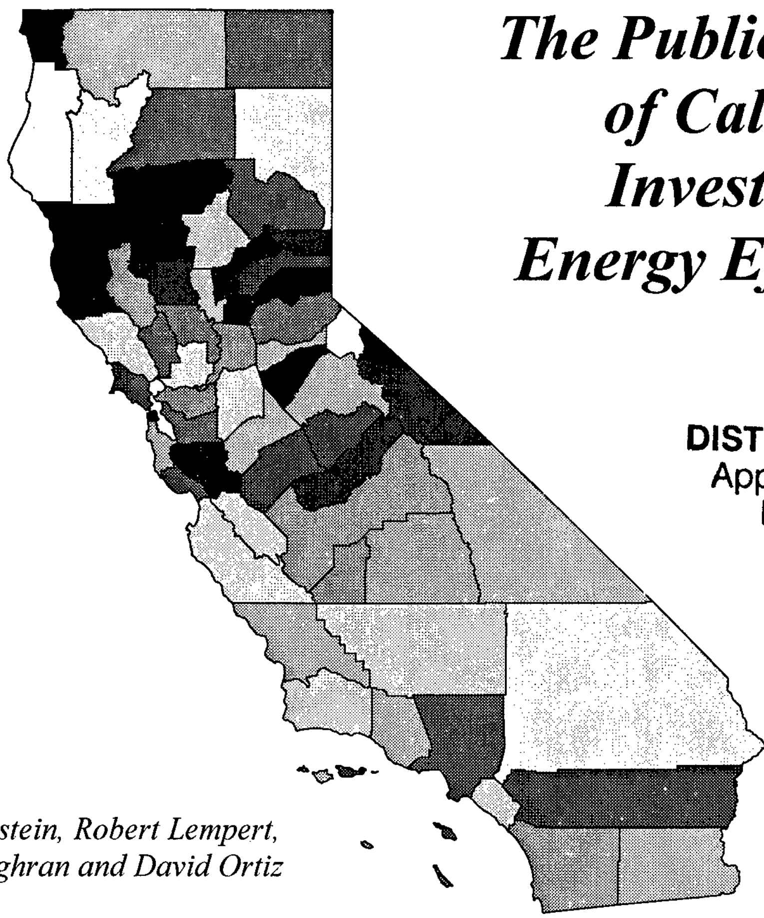

The Public Benefit of California's Investments in Energy Efficiency

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Mark Bernstein, Robert Lempert, David Loughran and David Ortiz

MR-1212.0-CEC

March 2000

Prepared for the
California Energy Commission

This is the final report of a project. It has been formally reviewed but has not been formally edited.

Science and Technology Division

Preface

In 1998, California became the first state to restructure its electric utility sector and allow consumers of electricity to choose their electricity supplier. At the same time, the state legislature created a "public goods charge," or a special fund, to promote energy efficiency, energy research, and alternative energy programs. This fund was created to replace the funding that traditionally had been allocated to energy efficiency programs by the electric utilities in the state prior to deregulation. The energy efficiency programs created since 1998 were initially managed by the California Public Utilities Commission (CPUC). For fiscal year 2000, the state legislature requested that the California Energy Commission (CEC) prepare a plan to transfer these programs from the CPUC to the CEC. To inform decisions regarding the size and scope of energy efficiency programs, the Governor requested that the CEC provide for an independent review of the public benefits of energy efficiency to the state of California. The CEC asked RAND, a nonprofit and nonpartisan research organization, to perform the independent assessment.

This report provides an economic assessment of the benefits of energy efficiency to the state of California and its citizens. This study is limited to improvements in the use of energy in the industrial, commercial, and residential sectors. Conceivably, improvements in energy usage in these sectors could yield a number of benefits, including economic gains, improved productivity, improved quality of service, higher reliability, reduced pollution, and lower costs to consumers, to name just a few. This report addresses only three of these benefits:

- Impacts on the gross state product of energy efficiency improvements in the commercial and industrial sectors.
- Impacts on air pollution of the improved utilization of energy in the commercial and industrial sectors.
- Impacts on households, particularly low-income households, of improvements in residential energy efficiency.

The Energy Efficiency Division of the California Energy Commission funded this study. The results can help inform policymakers and the general public about the benefits of energy efficiency programs in the state, help these readers to understand the role of the government in promoting these programs, and provide useful information for

national and local policymakers when they consider funding for their own energy efficiency programs in the future.

The authors would like to thank those individuals and organizations who helped in the researching and preparation of the report. A partial listing includes CEC Commissioners Robert Laurie and Robert Pernell; John Sugar, Lynn Marshall, Michael Messenger, Laurie ten Hope, and James Boyd of the CEC; and RAND's internal and external reviewers of the report.

This research was undertaken as a project of RAND's Science and Technology Division. Steven Rattien is the director of the Science and Technology Division. For further information on this report, please contact Mark Bernstein (markb@rand.org).

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Acronyms

AB	California Assembly Bill
AEE	Autonomous Energy Efficiency
CEC	California Energy Commission
CO	Carbon Monoxide
CPUC	California Public Utilities Commission
DOE	U.S. Department of Energy
DSM	Demand Side Management
EPRI	Electric Power Research Institute
GDP	Gross Domestic Product
GSP	Gross State Product
EIA	U.S. Department of Energy, Energy Information Administration
IOU	Investor Owned Utility
LBL	Lawrence Berkeley National Laboratory
LIHEAP	Low-Income Home Energy Assistance Program
LIEE	Low-Income Energy Efficiency
LIGB	Low-Income Governing Board
ORNL	Oak Ridge National Laboratory
NOX	Nitrogen Oxides
RECS	Residential Energy Consumption Survey
SIC	Standard Industrial Classification
SO2	Sulfur Dioxide
SOX	Sulfur Oxides
TFP	Total Factor Productivity
WAP	Weatherization Assistance Program

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Executive Summary

In the fiscal year 2000 budget, the California legislature requested that the California Energy Commission (CEC) prepare a plan to transfer energy efficiency programs financed by the public goods charge from their current home in the Public Utility Commission to the CEC. To inform decisions regarding the size and scope of energy efficiency programs, the Governor requested that the CEC provide for an independent review of the public benefits of energy efficiency to the State of California. The CEC asked RAND, a non-profit and non-partisan research organization, to perform the independent assessment.

In this report we address the public benefits of energy efficiency to California and find that improvements in energy efficiency lead to:

- A benefit to the state economy since 1977 that ranges from $875 per capita to $1300 per capita in 1998 dollars ($1998).
- Approximately 40 percent lower air pollution emissions from stationary sources.
- A reduced energy burden on low-income households.

Impacts on the state economy

This study measures the benefit to the state economy of improvements in energy efficiency in the industrial and commercial sectors from 1977 to 1995. It also predicts the potential future impacts of continued improvements in energy efficiency. The gross state product (GSP) per capita is our indicator of economic performance. The GSP measures the value of outputs from all economic sectors in the state. GSP per capita is 50 percent larger today than it was in 1979. The growth in GSP is due to a variety of factors, including but not limited to the industrial composition of the state, the growth of industry output, growth of commercial establishments, and demographic changes in the state. We use a conventional economic approach to measuring the growth in GSP per capita, in which state economic growth is correlated with the stock and flow of capital and labor, government policies, and the characteristics of the population. In addition we hypothesize that changes in energy intensity – the energy consumed per unit output – have also had an effect on the growth of GSP per capita.

Energy efficiency in California, 1977 to 1995

The energy intensity of the industrial and commercial sectors in the state has improved considerably, though not consistently, since 1977. The contributing factors to these changes are many. In the industrial sector, for example, the composition of the industrial sector has changed: the concentration of energy intensive industries in the state has declined and the corresponding change in energy intensity may not only be the result of improved energy efficiency. Increases in the price of energy from the late 1970s to the mid 1980s contributed to the declines in energy intensity. New technologies and California's building energy code also support improvements in energy efficiency and declines in energy intensity.

Our model indicates that if there had been no improvement in energy intensity from 1977 to 1995 that the California economy would have been three percent smaller than it was in 1995. In other words, the benefit in 1995 to the California economy from improvements in industrial and commercial energy intensity since 1977 ranges from $875 to $1300 per capita ($1998). The changes in energy intensity that lead to economic growth in the state are those that are independent of exogenous factors such as the price of energy and the composition of state industry. Hence, changes are those that could be the effect of government policy in the form of energy efficiency programs: from 1977 to 1995, California utilities spent a cumulative total of $125 per capita ($1998) on energy efficiency programs in the industrial and commercial sectors. Figure S.1 is a graph of the growth of GSP per capita from 1977 to 1995 and the estimated growth of GSP per capita in the absence of independent improvements in energy intensity. Audits of the energy efficiency programs have verified that energy efficiency improvements are real and contribute to reductions in energy intensity (Brown and Mihlmester 1994).

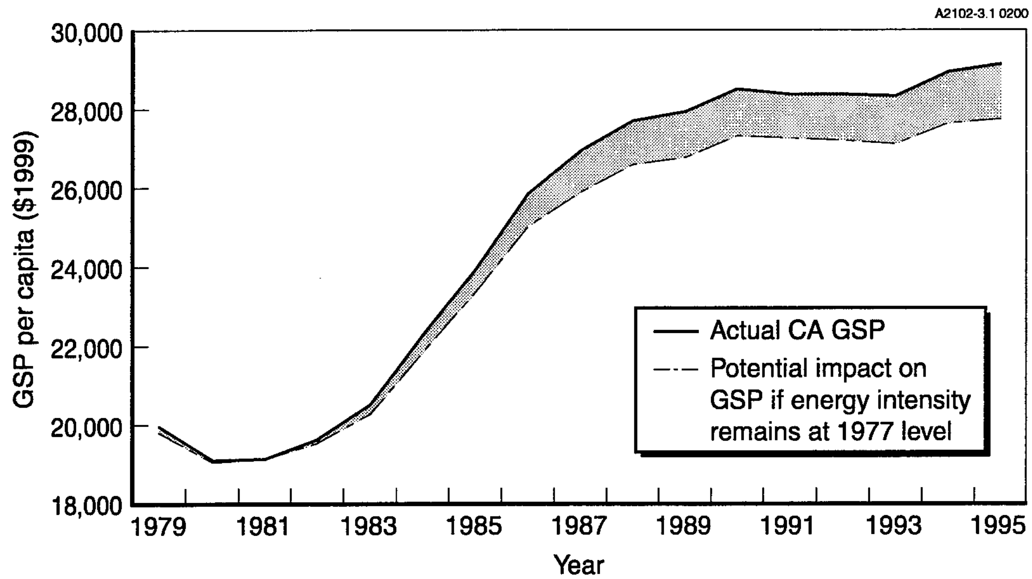

Figure S.1. Actual GSP ($1998) per capita from 1979 to 1995 and GSP per capita in the case of constant energy intensity.

Energy efficiency and the state economy – 2000 to 2010

California has achieved significant benefits from reductions in energy intensity since the late 1970s, but the future of energy use in the state is uncertain. Given CEC projections for energy consumption and independent assessments of the growth in housing and the state economy, projections for energy intensity in the state are expected to decline for the next decade (CEC 1998, Census 2000). However, there also exist indications that some of the drivers of lower energy intensity may reverse. It is widely believed that electricity industry restructuring will lead to lower energy prices: there may no longer be an economic motivation to encourage improvements in energy efficiency. Demographic projections predict population growth in inland areas, where cooling and heating loads are greater (see Figure S.2). Businesses located in these areas will require higher energy intensities than comparable businesses located in more moderate climates in the state. Lower energy prices and increased space conditioning load could lead to increases in energy intensity in all sectors.

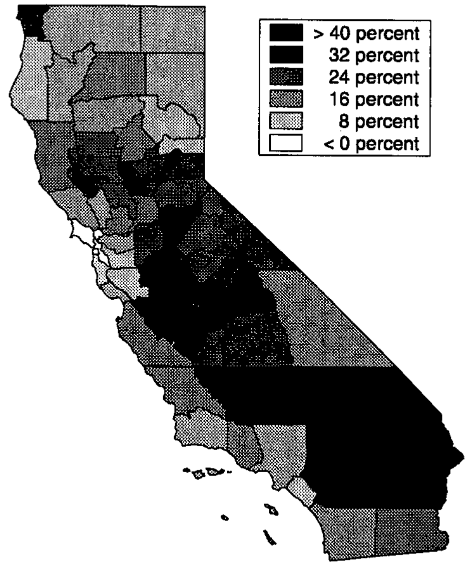

Figure S.2. Forecasted population growth by county from 2000 to 2010 (RAND 2000).

The analysis shows that reduced energy intensity does have an impact on economic growth. Energy intensity in the industrial and commercial sectors in California declined overall from 1977 to 1995. In the period from 1977 to 1985, there was a steep decline in energy intensity; from 1986 to 1995 energy intensity increased. If, in the absence of government-funded programs energy intensity were to increase at the 1986 to 1995 rate, GSP per capita in 2010 would be $300 per capita ($1998) less than it would have been if energy intensity remained at its 1995 level. On the other hand, if energy intensity were to decline at the 1977 to 1995 rate, the benefit to GSP in 2010 would be approximately $600 per capita ($1998). If energy intensity were to decline at the 1977 to 1985 rate, the benefit to GSP per capita would be approximately $1600 per capita ($1998). The particulars of the economic methodology caution us to interpret these estimates of the benefits of reduced energy intensity as upper bounds.

Environmental benefits

While there are numerous ways to measure environmental benefits, the most important benefit for California is the impact of energy efficiency improvements on air pollution emissions. If energy intensity in the state had remained at 1975 levels, air emissions from stationary sources in the state would be approximately 50 percent greater than

current levels. Reductions in energy intensity allowed California to slow the growth of emissions despite increases in energy consumption throughout the state.

Benefits to the citizens

Unlike energy intensity and GSP in the industrial and commercial sector, there is no easily quantifiable parameter with which to evaluate the benefits of energy efficiency to the residential sector. Furthermore, the economic benefits of reduced energy consumption in the residential sector are uncertain: modest increases in disposable income may not manifest themselves as large-scale economic benefits to the state. It is clear, however, that investments in energy efficiency do reduce energy costs and these investments are cost-effective. In California, improvements in residential energy intensity and energy prices have reduced the average energy expenditures per capita in real terms since 1980. These are benefits to California residents.

Low-income households derive the greatest benefit from reduced energy expenditures. While low-income households spend less on energy than higher income households, the burden as a percent of income is much higher for lower income populations (Figure S.3).

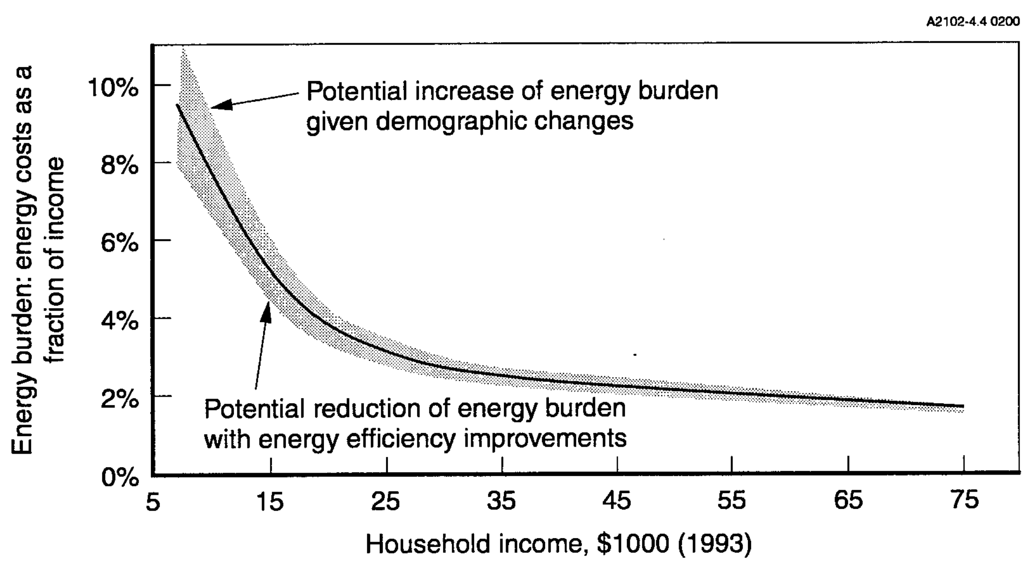

Figure S.3. California household energy expenditure as a percentage of income (EIA 1997).

On average, low-income households spend eight percent of their income on electricity, compared with two percent of a median-income household. In very poor households – those below 50 percent of the federal poverty level –23 percent of household income may be spent on electricity (Howat and Oppenheim 1999). Most of the energy-related services provided to these households are low quality, using inefficient appliances and inadequate heating and cooling. A 1993 survey found that low-income households spend more for water heating than median income households and spent almost as much on space heating, even though low-income homes are 40 percent smaller in size than their counterparts, on average (Colton 1994).

The opportunities for energy efficiency in the household can provide very direct benefits for low-income consumers. Simple changes such as insulation and appliance replacement can cut the energy burden by two percent or more. If the demographic drivers as shown in Figure S.2 continue, the burden on households will increase, and the potential benefits from energy efficiency could be four percent or more: $400 for a household with a $10,000 annual income. Energy efficiency programs at the household level provide two services: (1) they directly reduce monthly energy costs, thereby increasing the disposable income of the low-income population, and (2) they improve quality of life by improving the comfort level in homes. There are few government programs that can achieve both these goals.

Conclusions

Energy efficiency has provided significant benefits to the state and can continue to produce benefits into the future. In this report we do not evaluate the link between energy efficiency programs and improvements in energy intensity. Declines in energy intensity have resulted in increased economic growth in California and increases in energy intensity may result in slowed economic growth in the future.

1 Introduction

1.1 Legislative mandate

On 15 December 1999, the staff of the California Energy Commission (CEC) adopted the "Energy Efficiency Public Goods Charge Report" (CEC 1999). This report complied with Assembly Bill (AB) 1105[1], which directed the CEC to "conduct a public process to prepare a transition plan report and an operational plan report concerning the transfer of energy efficiency programs from the Public Utilities Commission to the State Energy Resources Conservation and Development Commission, and to submit these reports to the Legislature by January 1, 2000."

The CEC chose RAND as the organization to conduct an independent review of the public benefits of energy efficiency programs in accord with Governor Davis' budget comment of the legislation. The CEC then requested that RAND assess the public benefits that accrue from improvements in energy efficiency, and evaluate past and potential benefits.

1.2 Research approach

The current report is such an independent review of the public benefits of energy efficiency in California. The analysis will show that there is a quantifiable benefit of energy efficiency to the California economy and to California's citizens. We adopt a macroeconomic view of the California economy with energy intensity as an independent variable. Energy efficiency, in this context, is defined as those changes in energy intensity in the industrial and commercial sectors that are not due to economic or sectoral factors such as energy price, capital investment and climate. A second analysis studies the benefits of energy efficiency to the residential sector, with a focus on low-income households. Together, these two analyses allow us to determine the value of energy efficiency to the California economy and indirectly, the state's role in achieving that energy efficiency.

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[1] The relevant sections of the legislation appear in Appendix A.

The analysis method presupposes that one can disaggregate the role of energy efficiency in economic growth from other factors and applies only to the industrial and commercial economic sectors. Additional research is necessary to evaluate the validity of the underlying assumptions and the robustness of the economic analysis to modeling error. The value of energy efficiency to the residential sector defies macroeconomic analysis. Since the residential sector is responsible for approximately one third of the state's energy use it must be addressed. We address residential sector energy use with a focus on low-income households and conclude that energy efficiency has a value to the residential sector, albeit not directly quantifiable.

2 Trends in California energy consumption

2.1 Energy intensity

Energy efficiency is an enigma. What truly is a measure of energy efficiency? The Energy Information Administration (EIA) attempted to tackle the problem in 1995 with a publication entitled *Measuring Energy Efficiency in the United States' Economy: A Beginning* (DOE/EIA 1995). Since energy provides a number of services to consumers, the notion of energy efficiency can take on two complementary notions. An energy efficient appliance in a home, for example, can use less energy to provide the same level of service, or can use the same amount of energy to provide an increased level of service. In one case, less energy is used and the reduction can be measured directly. In the second case, the same amount of energy is used and to characterize the increase in efficiency requires a measure of comfort or utility – characteristics that elude succinct and accurate definition.

To avoid the snare of an ill-defined notion of energy efficiency, for the quantitative analysis in this report, like the EIA, we use measures of energy intensity as indicators of energy efficiency. Defined broadly, energy intensity is the energy used per unit output or unit served. An economy-wide indicator of energy intensity may be the energy per gross state product. In the commercial sector, where the primary energy load is for lighting and space conditioning, an appropriate measure of energy intensity may be the energy use per square foot, perhaps accounting for occupancy and employee hours. Each indicator has narrow applicability. In this context, changes in energy intensity reflect inverse changes in energy efficiency: when energy intensity decreases, energy efficiency increases. We must issue a caveat: a change in energy intensity does not necessarily reflect a change in energy efficiency. In the industrial sector, for instance, a change in energy use per dollar of gross state product may be due to changes in the mix of industries in the state or an increase in the price of energy rather than the investment in new equipment or energy technologies. What follows is a brief description of the trends in energy intensity in California, similarly large states, and the country. Chapter 3 is a

quantitative analysis of the value of reductions in energy intensity in the industrial and commercial sectors to the California economy.

2.1.1 Industrial sector

The industrial sector is that subdivision of the economy comprised of manufacturing, agriculture, mining, construction, fishing and forestry. Often, it is most easily identified by the Standard Industrial Classification (SIC) codes corresponding to these economic activities and as promulgated by the Department of Commerce. The DOE used a number of indicators of energy intensity to characterize changes in the energy consumption pattern in the industrial sector. These included energy use per gross product originating, per value added, per value of production and per industrial production (DOE/EIA 1995). In Chapter 3, we use only energy consumption per gross state product originating from the industrial sector. Figure 2.1 is a plot of energy intensity in the industrial sector in California, Florida, New York and Texas (the four largest states) from 1977 to 1995. California, Florida and New York have seen declines in energy intensity in the industrial sector.

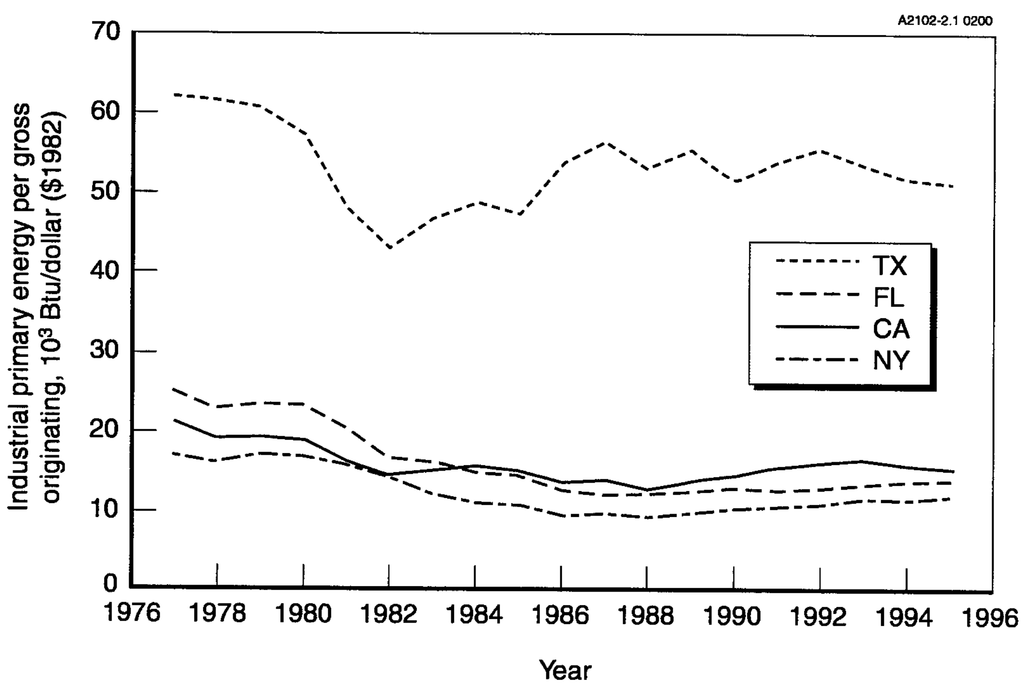

Figure 2.1. Industrial energy consumption per gross state product originating (DOE/EIA 1999; BEA 1999).

In Figure 2.1, we see that the energy intensity in Texas is appreciably higher than that in its peer states. The difference is due, in large part, to the mixture of industries that comprise the industrial sector in Texas as opposed to those in California, Florida or New York. There are certain industrial activities that require a significantly greater input of energy per dollar of output than others: petroleum products require significantly more energy than textiles, for example. Figure 2.2 is a plot of the fraction of the gross industrial product due to "energy intensive industry" from the four states of interest from 1977 to 1995. One can see from the plot that Texas does indeed have a larger share of its industrial product originate from so-called "energy intensive industry." In the analysis in Chapter 3, shifts in the composition in the industrial sector comprise an important control in the analysis.

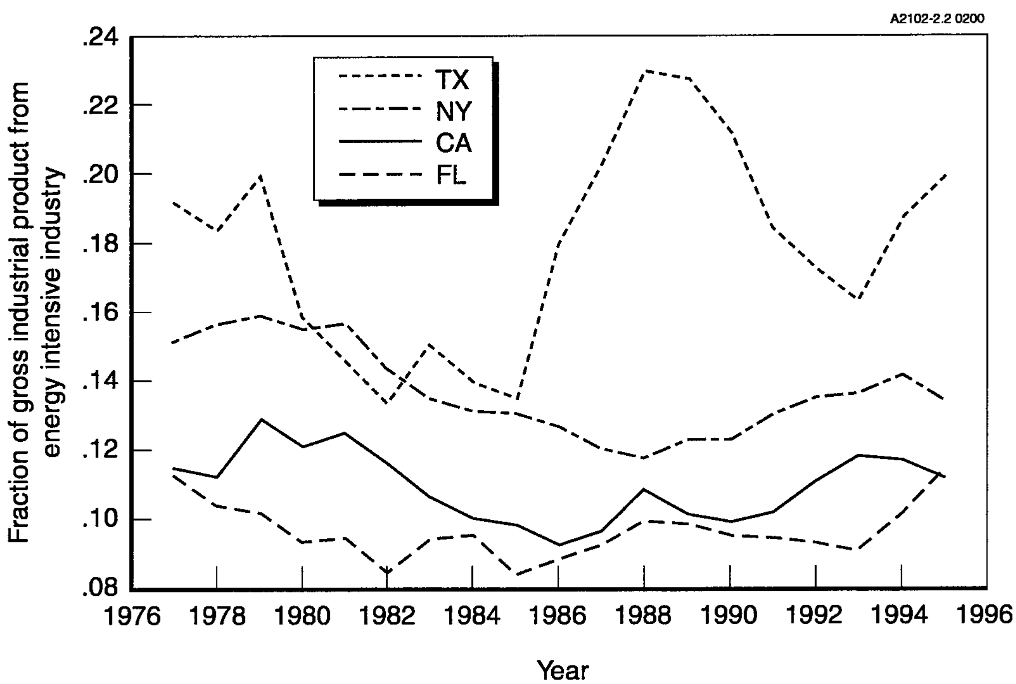

Figure 2.2. Fraction of gross industrial product from energy intensive industry. Energy intensive industries are mining (SIC 30000), stone, clay and glass (SIC 51320), primary metals (SIC 51330), paper products (SIC 52260), chemicals (SIC 52280), and petroleum products (SIC 52290). (BEA 1999).

2.1.2 Commercial sector

The DOE classifies the commercial sector as that economic sector that is "neither residential, manufacturing/industrial, nor agricultural (DOE/EIA 1998b)." A better definition is that regarding a commercial building; "commercial buildings include, but are not limited to, the following: stores, offices, schools, churches, gymnasiums, libraries, museums, hospitals, clinics, warehouses, and jails (DOE/EIA 1998b)." As in the case of the industrial sector, there are a number of indicators of energy intensity that may be used to characterize the commercial sector's utilization of energy. Figure 2.3 is a plot of the energy consumption per gross state product in the commercial sector in the four largest states. Compared to the industrial sector, there are marked differences in the patterns of energy intensity. California has had uniformly lower commercial energy consumption per gross state product over this time frame and has been able to keep pace with energy intensity improvements

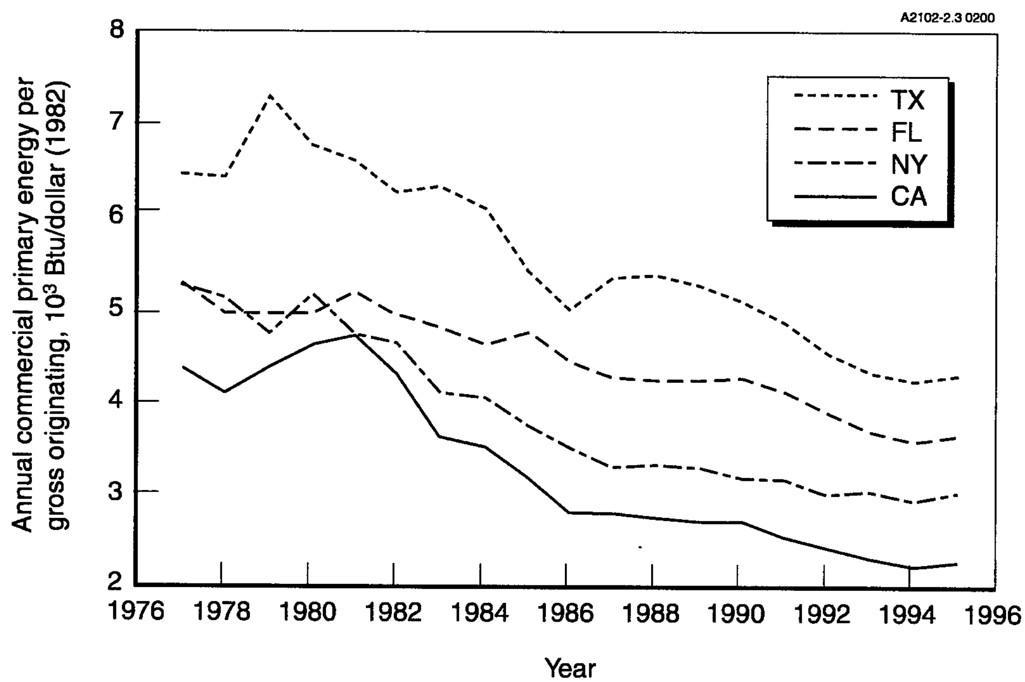

Figure 2.3. Commercial energy consumption per gross state product originating from 1977 to 1995 in California, Florida, New York and Texas (DOE/EIA; BEA 1999).

The commercial sector uses most of its energy for space conditioning and lighting. The energy used for lighting and space conditioning is a function, in part, of the amount of floor space in the commercial sector. Therefore, an alternative measure of energy intensity in the commercial sector is energy use per square foot. Figure 2.4 is a plot of the primary energy consumption per square foot in the four states of interest from 1977 to 1995. Inspection of Figure 2.4 reveals that commercial energy consumption per square foot in California has declined precipitously compared to that of Florida, New York or Texas after the early 1980s. The decline may be due to several factors, including the implementation of Title 24, the state's building energy code and California's temperate climate.

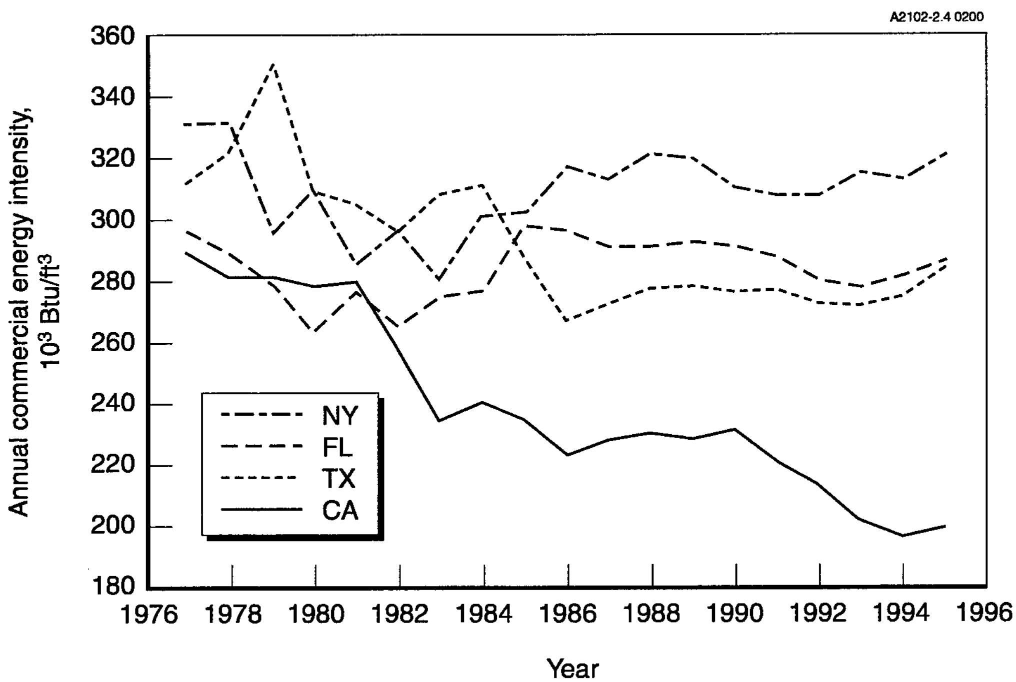

Figure 2.4. Primary commercial energy consumption per square foot of nonresidential floor space from 1977 to 1995 in California, Florida, New York and Texas (DOE/EIA; F.W. Dodge 1999).

2.1.3 Residential sector

Like the industrial and commercial sectors, the residential sector has a formal economic definition. In its initial report on energy efficiency in the U.S. economy, the DOE defined a number of indicators of energy intensity for the residential sector (DOE/EIA

1995). As mentioned previously, we will not engage the residential sector in a top-down, macro-level analysis of the benefits of energy efficiency. Rather, we will illustrate the value of reduced household energy consumption through trends in end-use energy utilization and household expenditures on energy services. Also, it is the residential retail electricity customer that may witness the greatest change in energy services due to electricity industry restructuring.

It is important, however, to understand general trends in household energy consumption before continuing the analysis. Figure 2.5 is the annual primary energy consumption per household and Figure 2.6 is the annual primary energy consumption per capita in California, New York, Texas and the U.S. from 1980 to 1995. Each Figure shows the same behavior: while California begins with a lower value of energy intensity in both cases, the indicator of energy intensity in California declines over the 15-year interval, while it increases in New York, Texas and throughout the country. Through examinations of the expenditures on energy in the residential sector, we will connect these declines in energy intensity to benefits to several classes of residential energy customers.

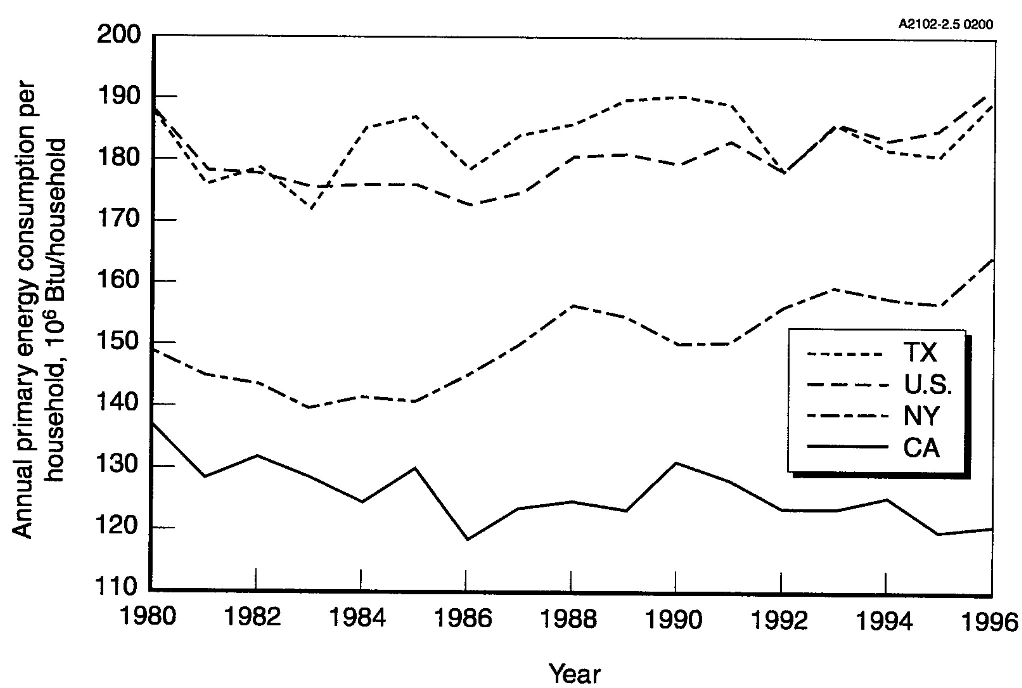

Figure 2.5. Annual per household primary energy consumption for the United States

and selected states (Census 1999b;
DOE/EIA 1999).

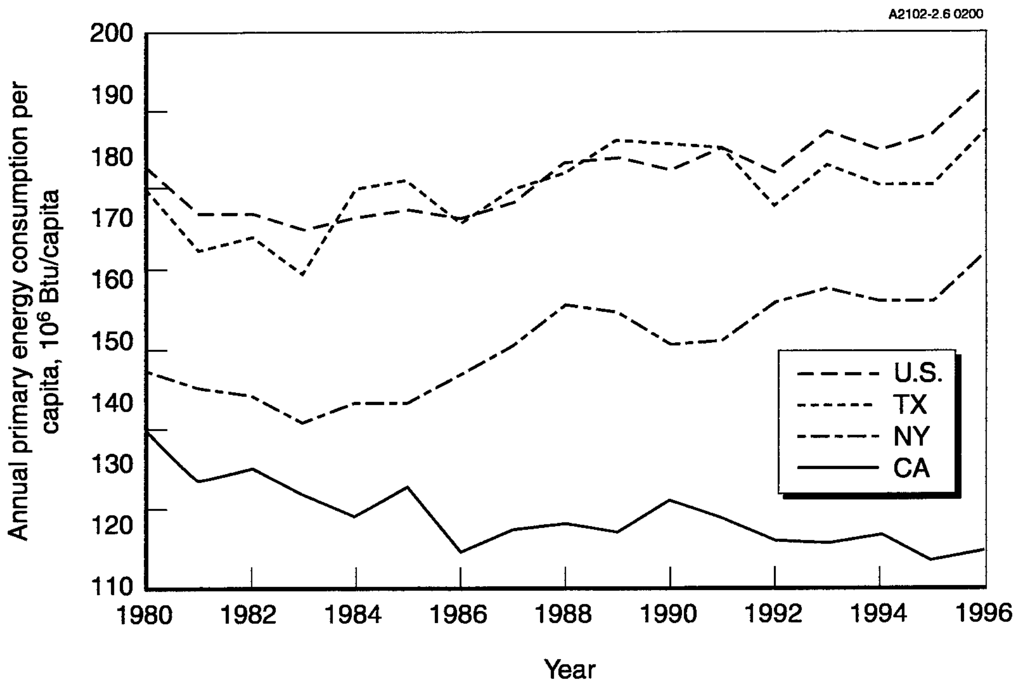

Figure 2.6. Annual residential per capita primary energy consumption for the United States and selected states (Census 1999a; DOE/EIA 1999).

2.2 *Energy consumption drivers: 2000-2010*

Section 2.1 compares energy intensity in California with that of the U.S. and several of its peers. Here we present a discussion of drivers of energy intensity that serve as a basis of our projections for the future effects of energy efficiency programs in California.

2.2.1 Industrial sector

From 1986-1995, California has seen the energy intensity of its industry rise (see Figure 2.1). The rise corresponds to reductions in the price of energy, the early stages of reductions in utility-sponsored demand-side management (DSM) programs, and a recession that decreased output value. CEC projections indicate that the fraction of California industrial output due to energy intensive industries will decline in the next decade (CEC 1998). The sectoral shift would naturally lead to a decline in energy intensity. However, the past declines in the energy intensity of the industrial sector

occurred during a unique combination of DSM programs and high energy prices. Of these factors, high-energy prices are not likely to occur over the next decade, and recent trends may cause energy intensity to increase.

2.2.2 Commercial sector

In the commercial sector, the CEC does not expect the energy intensity in the commercial sector to change appreciably through 2007 (CEC 1998). There are a number of reasons for this stagnation including demographic shifts to warmer areas and widespread use of the most inexpensive energy efficient building technologies. However an increase in commercial sector energy intensity is also possible. Not only are there an increasing number of electric devices in the commercial sector, but also there is a demographic shift (see Figure 2.7) to the warmer inland areas that will increase space-conditioning loads in the sector. Commercial sector energy prices are also expected to decline (CEC 1998), removing price as a motivator for improving energy efficiency. As in the industrial sector, the analysis in Chapter 3 will consider energy intensity as one of several factors contributing to economic growth in the state.

2.2.3 Residential sector

New homes in California comply with Title 24, the state residential energy code. However, Title 24 does not regulate many of the new electric devices and smaller appliances that may contribute to increased energy use. Population shifts and the increased number of end uses in the residential sector may contribute to dramatic increases in energy consumption in the residential sector. Despite the presence of these factors, the CEC expects energy intensity in the residential sector to decline slightly over the next decade as it has since 1985 (CEC 1998). Shifts in the residential sector are not independent of shifts in the industrial and commercial sectors, and the discussion that follows also applies to those sectors.

While the population throughout California is growing, the areas of expansion in the next decade will be in the interior rather than the coast. These areas are warmer during the day, colder at night, and require a greater energy load for space conditioning than the temperate coastal regions. The map below gives an indication of the expected

growth in population by county. The shift of population and the development of the interior of the state may result in significant increases in energy consumption across all sectors as businesses follow population and vice versa.

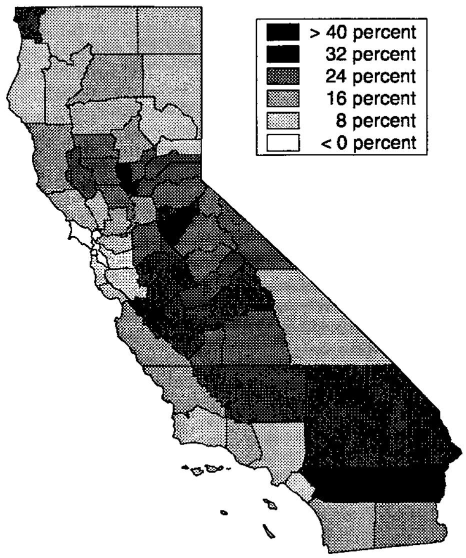

Figure 2.7. Forecasted population growth by county from 2000 to 2010 (RAND 2000).

2.3 Energy demand and reliability

The preceding reveals an important fact: energy demand, especially electricity demand, is rising. The CEC's Baseline Energy Outlook forecasts a growth rate of electricity demand of 1.8 percent and a growth rate of peak load of 1.7 percent through 2007 (CEC 1998). The increases in the residential sector are due to population growth and demographic shifts in the state. The CEC expects energy demand to rise significantly in the industrial and commercial sectors as well. Increases are expected in industrial demand for natural gas for industrial processing and in agricultural electrical demand for water pumping and processing. The commercial demand in the state will expand commensurate with the overall economic growth of the state and will follow the trends of the residential sector regarding geographic placement.

Recent economic development throughout the west contributes to regional energy reliability problems. As a member of the Western Systems Coordinating Council (WSCC), California shares an electricity transmission network with Washington, Oregon, Idaho, Montana, Wyoming, Nevada, Arizona, Utah, Colorado and New Mexico. The

reserve margin is a measure of the ability of the transmission system to handle unexpected increases in load. The California/Southern Nevada sub region of the WSCC has a 10-year average firm non-coincident peak demand reserve margin of 13.8 percent. The margin includes those customers whose service the utility may curtail under peak load conditions. If these interruptible consumers receive service, the reserve margin drops to 3.7 percent (CEC 1999). Restructuring in the electricity industry places a premium on the efficient use of resources, and reserve margins can be expected to decline as restructuring continues throughout the region. In addition, in part because of its size and climatic diversity, peak loads in California are coincident with peak loads in various regions of the WSCC. The economic growth of these regions may limit the ability of California to import electricity to meet regional coincident demand. The North American Electric Reliability Council concluded that

> The Arizona-New Mexico-Southern Nevada and the California-Mexico areas of the WSCC may not have adequate resources to accommodate a widespread severe heat wave or a significantly higher-than-normal forced outage rate for generation. Those areas are experiencing a continuing trend of peak demand growth exceeding the addition of new generation facilities (NERC 1999).

Energy efficiency in California has the potential to lessen the impacts of regional peak demands on California consumers.

2.4 Environmental pressures.

In the same way that the growth and shifts in population in California will determine the future energy demand in the state, so will they determine future environmental pressures. Regional population densities and the geography of California conspire to exacerbate problems in air quality due to energy use. The primary contributor to decreased air quality throughout the state is motor vehicles, but emissions from electricity production and industry also contribute. The California Air Resources Board (CARB) collects and disseminates data on state air quality. For each pollutant, the CARB assigns attainment and non-attainment zones throughout the state: in a non-attainment zone, the concentration of the pollutant fails to meet the standards of the Clean Air Act (CARB 1999). Figure 2.8 is a map of the attainment and non-attainment zones for atmospheric ozone. Inspection of Figure 2.7 and Figure 2.8 reveals that in those areas in which the

population of the state is expected to grow, levels of atmospheric ozone are already beyond those commensurate with the current specification. The attainment zones for CO, NOx, SO2 and particulates have different statewide distributions. However, major metropolitan areas uniformly fail to meet air quality specifications (CARB 1999). It is important to note that the air quality is time dependent and periods of poor air quality are the result of natural and anthropogenic causes. In addition to statewide air quality concerns, California is also subject to regulation under the acid rain program of the Clean Air Act. Since California is the second largest consumer of energy at the state level, it will bear a significant burden for carbon emission reductions in accordance with the Kyoto Protocol.

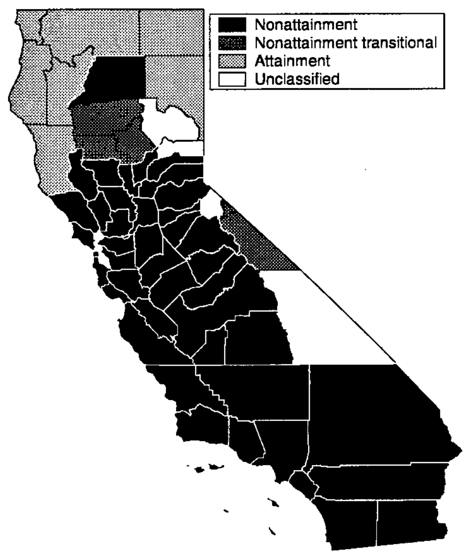

Figure 2.8. Attainment and non-attainment zones for atmospheric ozone by county in 1999 (CARB 1999). The map is a county-by-county approximation of the California air basins.

2.5 Conclusions

The only certainty with respect to California's energy use is that it will increase. The interplay of prices, government regulations and efficiency programs, climate and economic factors that contributed to historic declines in energy intensity may not be present in the future. In the chapter that follows, we show that the declines in energy

intensity in the industrial and commercial sectors have had significant positive benefits for California's economy.

3 Energy efficiency in the industrial and commercial sectors and economic growth

Energy is a component, directly or indirectly, of every product in the marketplace. Glass and steel are products of processes requiring tremendous heat that transform raw materials into gleaming finished products. Gasoline and kerosene, the most recognized mobile sources of energy, are the result of energy-intensive distillation processes. Given that these products use significant amounts of energy, it is obvious that reductions in energy intensity should decrease production costs. For the less-intensive energy users, do reductions in energy intensity benefit the bottom line? Do more efficient motors significantly reduce costs for textile manufacturers? Does an energy efficient photocopier improve the bottom line of a small internet-based company?

To perform a cost accounting of each industrial and commercial component – and to identify each and every energy efficiency opportunity – would be an actuarial exercise beyond the scope of this report. However, we can identify the overall effects of energy efficiency on the California economy. We consider the commercial and industrial sectors together as the primary drivers of economic output of the state. Under the assumption that the economic performance of each sector is in part due to its energy intensity (as discussed in Chapter 2), we determine the role of changes in energy intensity on the economic growth of the state from 1977 to 1995.

In addition to the analysis for the period 1977 to 1995, we look to the future. Improvements in energy efficiency often coincide with improvements in industry practice and investment in new equipment and processes. However, with the rapid advance of technology and changes in energy services, it is possible that the gains in energy intensity in California may reverse, as highlighted earlier. We close with a set of scenarios based upon possible changes in energy intensity in the commercial and industrial sectors.

3.1 Energy efficiency and analysis methodology

We hoped that there would be a well-accepted definition of energy efficiency that we could employ for our quantitative analysis. Such a definition would have been common to the policymakers of the CEC and the legislature and easy to measure for

manufacturing energy managers, building owners, builders and homeowners. Such a definition does not exist. In 1995, the EIA published a report entitled *Measuring Energy Efficiency in the United States' Economy: A Beginning*. According to the EIA:

> In the absence of consistent defensible measures, energy efficiency is a vague, subjective concept that engenders directionless speculation and confusion rather than insightful analysis (DOE/EIA 1995).

The EIA defined energy efficiency concepts that it used in its analysis. These concepts are:

a. Increases in energy efficiency take place when either energy inputs are reduced for a given level of service or there are increased or enhanced services for a given amount of energy input.

b. Energy efficiency is the relative thrift or extravagance with which energy inputs are used to provide goods or services (DOE/EIA 1995).

The first concept listed above implies that an appropriate quantitative definition of energy efficiency would be a ratio of energy consumption and services rendered. Energy intensity, as presented in Chapter 2, is such a ratio. Energy intensity, when used as a proxy for energy efficiency consistent with "concept a," is inversely proportional to energy efficiency: Reductions in energy intensity represent increases in energy efficiency.

While energy intensity serves as a convenient proxy for energy efficiency, we also focus our efforts on isolating exogenous changes in energy intensity from those changes due to energy efficiency improvements. The measure of energy intensity we use is the primary energy consumption[2] per GSP (from either the industrial or commercial sector as appropriate.) However, energy intensity is dependent upon a number of factors, including the price of energy, the mix of industries in a state, the investment in new equipment, the size of industrial and commercial buildings, and climate. To separate changes in energy intensity due to efficiency improvements and changes in energy intensity due to exogenous factors requires us to expand the scope of the analysis beyond California and consider the changes in energy intensity among many states, only

[2] Primary energy is the energy delivered to an end user accounting for the generation, transmission and distribution of the energy; the CEC offers a succinct definition (CEC 1995). Using primary energy in this analysis allows us to aggregate all fuels used in the industrial and commercial sector into one measurement of energy consumption.

returning later to consider California as a special case. The quantitative analysis proceeds in two general stages. In the first, we identify the determinants of energy intensity in the states; in the second, we relate changes in GSP to changes in energy intensity and account for the exogenous determinants of energy intensity.

Both the numerator and denominator of our measure of energy intensity are comprehensive measurements: Energy consumption represents all fuels consumed in the industrial and commercial sectors, and GSP measures the total output in these sectors. In the same way that one can separate the components of both energy consumption and GSP, we must account for these components when we analyze changes in energy intensity. Consider a hypothetical example: Two states have the same industrial GSP, but one derives most of its industrial product from petroleum refining, the other from textiles. Assume further that the industries in each state use the most advanced and energy efficient equipment available. Despite the energy efficient equipment in both states, the first state will have greater industrial energy intensity than the second. Take a slightly different version of the previous example in which the two states have the same GSP and the same industrial composition. However, in this case, the first state's industry has older, less-efficient equipment, and the second state's industry has new, more efficient equipment. For this example, the first state will once again have greater industrial energy intensity than the second.

There are additional factors that may influence the energy intensity of one state more than another. Energy may be viewed as an input to production, and a higher price of energy in a state may cause industry and commercial firms to update equipment to realize savings in energy expenditures: The result is reduced energy intensity. With modifications, the same comments apply to the commercial sector. We use the same measure of energy intensity in the commercial sector that we use in the industrial sector: energy use per gross output, and we identify the effects of commercial building construction upon energy intensity. In addition, in both the industrial and commercial sectors, different climate zones may contribute to differences in energy intensity.

To measure the growth of GSP, we use a conventional economic approach in which per capita state economic growth is correlated with the stock and flow of capital and labor, their quality, and government policies. We hypothesize that energy intensity,

which is a direct input in the production process, therefore has an effect on economic growth. We quantify changes in GSP due to changes in energy intensity while controlling for a number of factors, including energy price, the composition of the industrial sector, the investment of new capital and buildings, and climate. By design, the identified effects of energy intensity on GSP are independent of the controlled factors.[3] Our results, from an assessment of all 48 contiguous states, show that reductions in energy intensity do lead to increases in GSP. Table B.3 in Appendix B summarizes the results.

As state economies become less energy intensive, the growth rate of their GSP increases. According to the analysis, a ten percent decrease in the rate of growth of industrial energy intensity leads to a 0.23 percent increase in the rate of state economic growth; a ten percent decrease in the rate of growth of commercial energy intensity leads to a 0.17 percent increase in the rate of state economic growth (see Appendix B). The changes in energy intensity are those changes that are independent of control factors such as the price of energy, the state industrial composition, capital investments and climate. Given the control factors, the hypothesis is that the estimates of economic growth due to declines in energy intensity capture changes to technological change, standards and other related effects. Note however, that energy intensity could change for other unidentified reasons and that absolute declines in energy intensity may not always lead to economic growth. Furthermore, energy intensity may in fact be dependent on the control factors. The results are not causal and we caution the reader to interpret the estimated relationship between energy intensity and state economic growth as an upper bound on the economic benefit of energy efficiency.

3.2 Energy efficiency and the California economy, 1977-1995

We now turn to the special case of California. The econometric analysis, presented in its entirety in Appendix B, determines the average effect of energy intensity and other

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[3] An auxiliary analysis in Appendix B identifies the determinants of energy intensity. Energy price, capital expenditures, climate and industrial composition accounted for approximately one third of the variation in energy intensity. The trends in individual states and time trends accounted for approximately 55 percent variation. The remaining fraction of the changes in energy intensity—about 12 percent—is independent of

factors on GSP in the 48 contiguous states. To determine the benefits for California, we use the national averages on data from 1977 to 1995 as a baseline for determining the effects of changes in California's energy intensity on California's per capita economic growth.

Table 3.1. The benefit of energy intensity improvements to the California economy.

Estimate of effect of energy intensity on the economy	Increase in GSP per capita ($1998)	Increase in total GSP (billions $1998)
National average	$876	$28.1
States similar to California	$1,363	$43.7

From 1977 to 1995, GSP per capita in California grew from $19,595 to $29,128 ($1998). The analysis shows that changes in energy intensity played a role in the growth of GSP. According to the analysis, if energy intensity had remained at the 1977 level over this period, then GSP per capita would have been 3 percent less than its 1995 value. The results imply that reductions in energy intensity – independent of economic factors – have contributed to economic growth of $876 per capita ($1998) (see Table 3.1). When we examine the impact of energy intensity across states with industrial characteristics similar to California, we find that the impact on GSP per capita is potentially larger than the national average. In this case, the increase in GSP per capita due to reductions in energy intensity is $1,363 per capita ($1998). Figure 3.1 shows the actual evolution of GSP per capita and the predicted evolution in the case of constant energy intensity.

the economic, state and time variables. This fraction can be interpreted as the change in energy efficiency influenced by government policy.

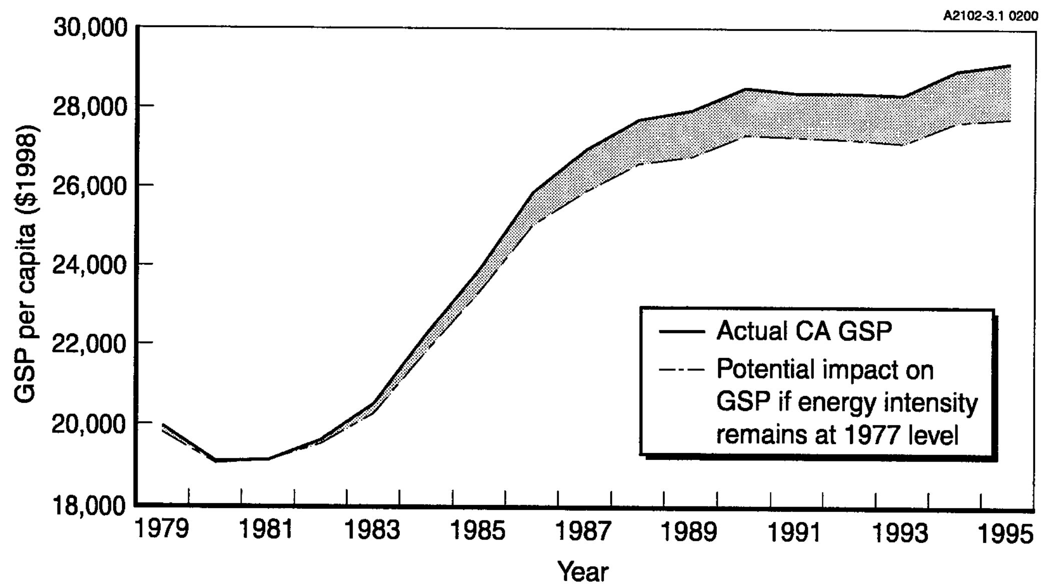

Figure 3.1. Actual GSP ($1998) per capita from 1979 to 1995 and GSP per capita in the case of constant energy intensity.

3.3 The value of energy efficiency programs to California, 1977-1995

Throughout this time period, there have been state- and utility-sponsored energy efficiency programs. Often, these programs target specific end-users and end-uses such as lighting, home insulation, and facility retrofitting. The purpose of the programs is to promote cost-effective energy efficiency improvements in California's industries, stores, offices, farms, and homes. The extent to which the programs have contributed to declines in sector measures of energy intensity is unknown.

According to the analysis outlined in Section 3.2, declines in energy intensity result in increases in GSP. It is relevant to ask how the increases in GSP compare to estimates of energy and monetary savings from state-sponsored energy efficiency programs. Unfortunately, the data that describes the expenditures and energy savings of state-sponsored DSM programs is limited. Investor owned utilities (IOUs) are required by law to file expenditure reports and savings estimates with the CPUC. Municipal utilities, such as the Los Angeles Department of Water and Power and the Sacramento Municipal Utility District, are not required to file any DSM expenditure or savings reports. Furthermore, programs may target one or several end use sectors. Given CPUC filings by IOUs and voluntary reporting on the part of municipal utilities, the CEC is able

to estimate the amount of DSM funds that were spent in the industrial and commercial sectors. These estimates, however, are approximations and not measured quantities. Through 1995, the present value (discounted at 5%) of DSM expenditures in these sectors was estimated to be over $4 billion ($1998) or $125 per capita ($1998). The previous section showed that since 1977, reductions in energy intensity have resulted in economic gains of approximately $875 per capita ($1998), which we do not directly attribute to the energy efficiency programs. To achieve a positive return on investment, DSM programs needed to account for approximately one percent of the energy saved due to changes in energy intensity (see Table 3.2). It is assumed that the energy saved is the result of changes in energy intensity independent of the control factors. The CEC has estimated that the cumulative energy savings of DSM programs in the industrial and commercial sectors was 546 TWh, which is approximately two percent of the cumulative energy savings due to reduced energy intensity from 1977 to 1995. The estimated energy savings, however, do not account for the control factors: the estimated savings may be due to changes in labor and capital. If the energy efficiency programs achieved their energy savings in methods commensurate with the statistical analysis in Appendix B, the cumulative return on investment ranges from 80 to 170 percent[4]. To identify a return on investment from energy efficiency programs that meets the assumptions of the economic specification in Appendix B will require additional analysis. It is important to note that the notion of a return on investment in this context applies to the state economy as a whole and not to those who participated in energy efficiency programs in particular.

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[4] The low value corresponds to the national average of effect of industrial and commercial energy intensity on the state economy. The higher value corresponds to the upper limit of the statistical identification (see Appendix B.)

Table 3.2. Estimates of the value of energy efficiency in the industrial and commercial sectors to California from 1977 to 1995.

	Estimate of effect of decreased energy intensity on increased economic growth	
	National Average	Higher Impact
Share of energy savings required for DSM programs to breakeven	1.09%	0.73%

3.4 Future benefits of energy efficiency to California

AB 1105 directed the CEC to develop an operational report to investigate the transfer of the energy efficiency programs from the PUC to the State Energy Resources Conservation and Development Commission. The transfer presupposes that the funding will continue. In the previous section, we have shown that improvements in energy efficiency, perhaps influenced by government programs, have resulted in economic benefits to the state. In what follows, we project our results into the future and determine the future value of energy efficiency when making some assumptions regarding future changes in energy intensity. These projections cannot be tied directly to the future spent funds, but they do allow us to speculate regarding the continued benefits of energy efficiency to the California economy.

Inspection of Figure 2.1 and Figure 2.3 reveal three general trends in energy intensity in California. From 1977 to 1995, energy intensity in both the industrial and commercial sectors declined. The average behavior hides two phases of energy intensity changes. From 1977 to 1985, energy intensity in California declined quickly. From 1986 to 1995, the average energy intensity rose. The phases of change in energy intensity are due in part to higher energy prices in the early 1980s and lower real energy prices from the late 1980s to the present. We can extrapolate each of the three trends into the future to form scenarios for future exploration. Figure 3.2 presents the three scenarios as trends in energy intensity changes for the industrial and commercial sectors. In one scenario, energy intensity increases as it did from 1986 to 1995. In the second scenario, energy

intensity declines moderately according to the 1977 to 1995 average change. In the third scenario, energy intensity declines according to the 1977 to 1985 trend.

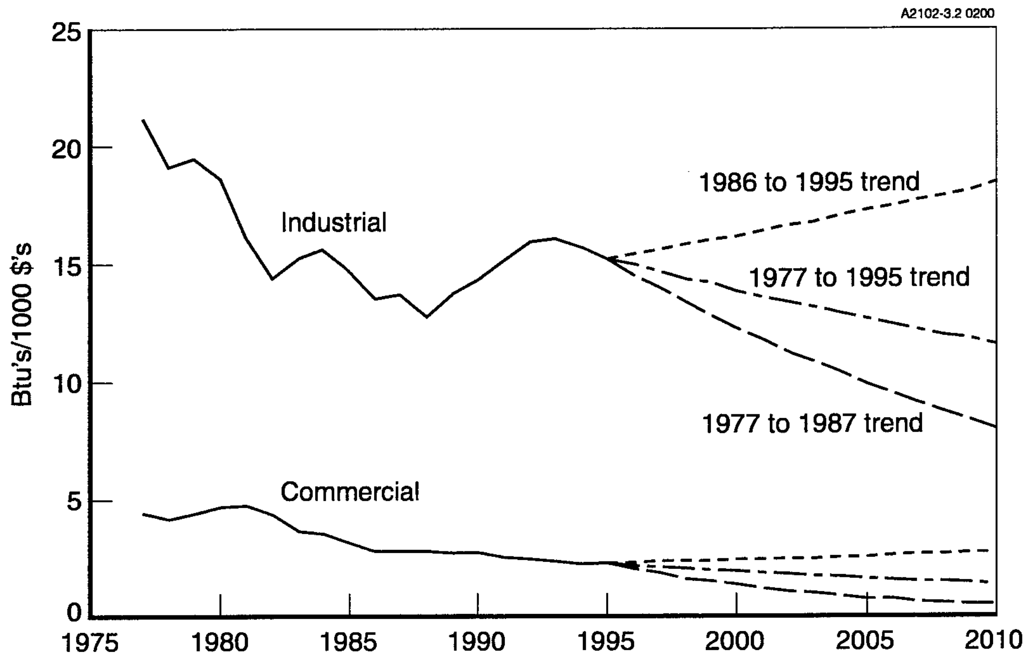

Figure 3.2. Trend of primary energy intensity in California in the industrial and commercial sectors.

The analysis in Section 3.2 can be used to calculate the expected economic growth for the three scenarios. We calculate an expected change in GSP per capita for the three scenarios – and we also use low, medium, and high estimates for the effect of energy intensity on the state economy based on the standard error of our analysis. We compare these nine estimates against a baseline that assumes no change in energy intensity from 1995. Table 3.3 presents the nine estimates of the changes in GSP per capita based on scenarios of the commercial and industrial sectors combined. If energy intensity in the commercial and the industrial sectors increases as it did after 1986, the cumulative net loss in GSP per capita by 2010 could be about $300 per capita ($1998) as compared to the baseline. On the other hand the analysis shows that reductions of energy intensity can continue to have large-scale economic benefits to the state. If energy intensity in California continues to decline at its average rate from 1977 to 1995, we could expect an additional increase in GSP per capita of anywhere between $98 and $1,112 per capita ($1998), depending on the estimated benefits of decreased energy intensity.

Table 3.3. Estimates of future economic benefits of reductions in energy intensity to California in terms of per capita GSP ($1998).

Estimate of the effect of energy intensity on the California economy	1995 Benefits	2010 Changes in GSP per capita from 1995		
		1986-1995 trend Increase in energy intensity	1977-1995 trend Moderate decrease in energy intensity	1977-1985 trend Large decrease in energy intensity
Higher Impact	$1,331	-$534	$1,112	$3,101
National Average	$876	-$302	$597	$1,622
Lower Impact	$470	-$68	$98	$226

If one believes that there is a chance that energy intensity could worsen in the absence of government policy, that the energy intensity increases when compared to the 1986 to 1995 period, and that energy efficiency programs can achieve improvements similar to those made since 1977, the potential benefit is $900 per capita (the difference of the average values in column 4 and column 3 of Table 3.3.) In a state of 36 million residents (RAND 2000), the potential gain in GSP could range from $6 billion (using the low values under these same assumptions) to $60 billion (using the high values under these assumptions). For 2001 to 2002, the CEC has requested $270 million to continue the programs.

3.5 Environmental benefits of reduced energy intensity

Energy consumption directly leads to the emissions of air pollutants. In addition to the economic benefits, reductions in energy intensity have slowed the increase in air pollution throughout the state. Figure 3.3 shows the 1995 pollution emissions in California from stationary sources other than waste disposal.[5] These emissions totaled approximately one million tons (CARB 1997). If energy intensity had remained at 1977 levels and the mix of energy uses remained constant, the estimated emissions of pollutants from these sources would have been more than 1.6 million tons. Though mobile sources are the primary contributors to pollutant emissions, the emissions savings from stationary sources is significant.

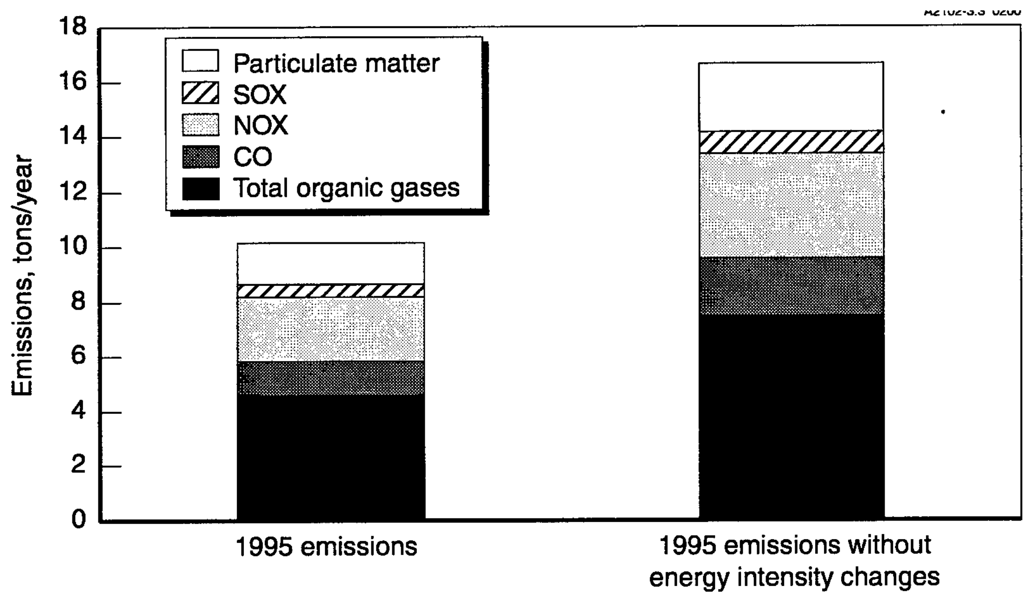

Figure 3.3. Estimated pollutant emissions from all stationary sources excluding waste disposal (CARB 1997).

[5] We include particulate matter, SOX, NOX, CO and total organic gases.

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4 Benefits of energy efficiency in the residential sector

The results of the previous chapter are predicated upon the assumption that changes in GSP are indicators of the benefits of energy efficiency to the state. The assumption is reasonable because the output of the industrial and commercial sectors is, by definition, the economic output of the state. Unfortunately, there does not exist a satisfactory analogous measurement with which to quantify the benefits of energy efficiency to the residential sector; the following discussion presents a number of benefits that have come to California households due to reductions in household energy intensity, including financial savings, comfort and an increased number of energy services. When we compare these and other characteristics of household energy consumption and expenditures in California with those of other states and across income levels, we find that reductions in household energy intensity have had significant benefits for the state's citizens.

4.1 Residential energy consumption characteristics

Like changes in energy intensity in the industrial and commercial sector, changes in residential energy intensity are due to a number of factors that include, but are certainly not limited to, climate, size of household – both in persons and area – single or multiunit, the age of the home and its appliances, the presence and enforcement procedures of a residential energy code, the price of energy and so on. In Section 2.1.3, we presented two energy intensity indicators for the aggregate residential sector: primary energy consumption per household and primary energy consumption per capita in the four most populous states. As mentioned before, California benefits from a more temperate climate and a stricter residential energy efficiency code than the other states, which are reasonable explanations of the observation that California's residential energy consumption per household and per capita is uniformly lower than other states. To compare the states, consider changes in energy intensity as a gross indicator of changes in energy efficiency in the residential sector. Remember that these numbers represent gross changes only and do not account for exogenous factors. Table 4.1 lists the percent changes in per capita primary energy consumption in California, Florida, New York and

Texas. Also included is the year in which the state adopted a residential energy efficiency building code (through 1995, Texas had not adopted a code.) Primary residential energy consumption per capita in California has fallen by almost 20 percent since the 1970s whereas in Florida, primary energy consumption per capita has risen 17.5 percent. The average change in annual per capita energy consumption for the 48 contiguous states over the same time interval is a 1.7 percent increase.

Table 4.1. Changes in residential primary energy consumption per capita excluding transportation (Ortiz and Bernstein 1999).

State	Year of residential energy code implementation	Percent change in per capita energy consumption from 1970-1978 average to 1988-1995 average
CA	1978	-19.2
FL	1980	17.5
NY	1979	-3.5
TX	N/A	3.9

The changes in per capita energy consumption have reduced real per capita energy expenditures in the state. The 1995 residential energy expenses per capita in California were $363 ($1995) (DOE/EIA 1998a). The 1995 expenses represent a decline in real energy expenses from the high of $415 ($1995) in 1982. The history of real residential energy expenses appears in Figure 4.1. The $52 per capita savings per year from 1982 to 1995 translates into a gross savings to California residents of $1.66B. This comprises a combination of both improvements in energy efficiency as well as energy prices, which have not increased in real terms.

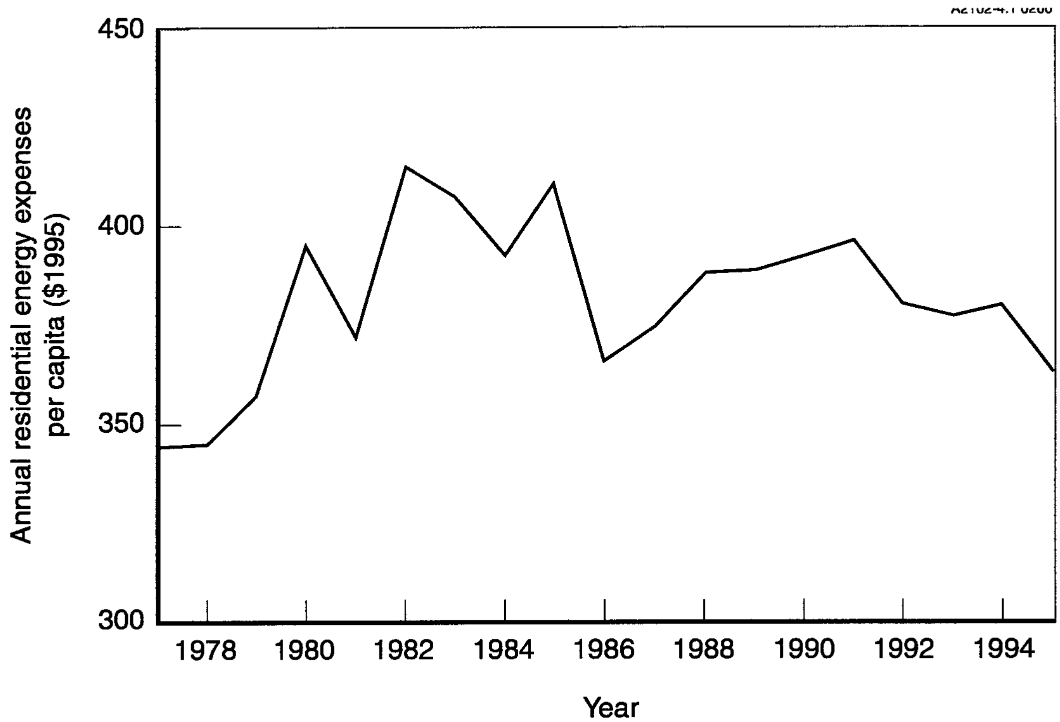

Figure 4.1. Real energy expenses per capita in the residential sector in California from 1977 to 1995 (DOE/EIA 1998b).

4.2 Energy efficiency and low-income households

In the analysis of the industrial and commercial sectors, we assume that the firms that constitute these sectors optimize their operations to minimize costs. Therefore, the savings due to reduced energy use are always reinvested in the interests of the firm. In California's residential sector, even if we assume that $52 per household member to be a correct value for the annual savings due to lower energy intensity, we cannot make the argument that this money finds itself reinvested in a similar way. One contributor to the difficulty is the differing energy needs of households. Annual energy expenditures for most households falls between $1000 and $2000. While it is true that higher-income households tend to use more energy than lower-income households, the percentage of household income devoted to energy services is far greater for low-income households. According to the 1997 Residential Energy Consumption Survey (RECS), the average energy expenditures for a household in the $5,000 to $9,999 income bracket were $985 ($1997). However, for a household in the $75,000 and above income bracket, the

expenditures were $1,835 ($1997); see Figure 4.2 (DOE/EIA 1999). Average energy expenditures in the highest income group are approximately twice that of the lowest income group even though their income is more than seven and a half times greater.

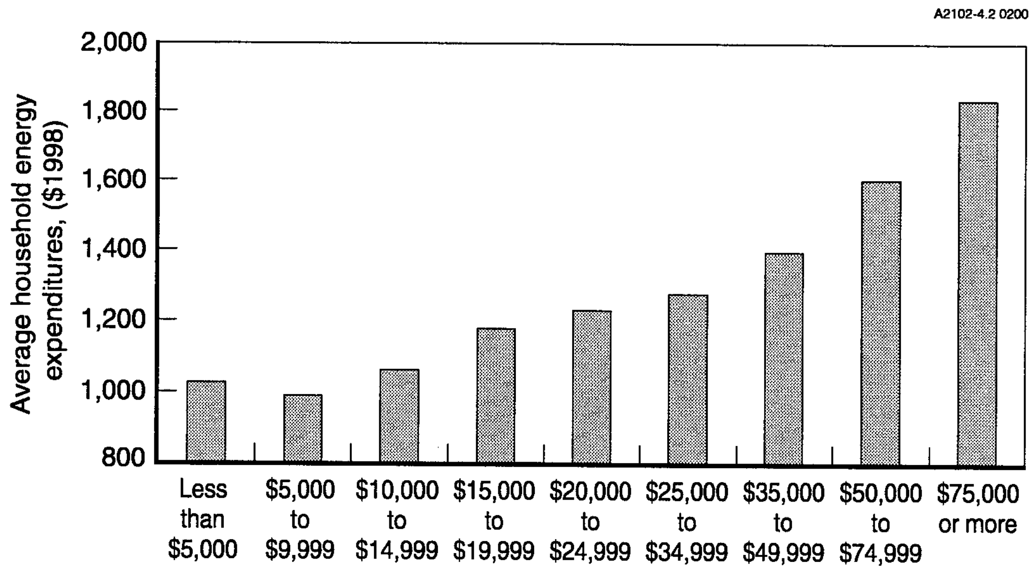

Figure 4.2. Nationwide average energy expenditures per household by income level (DOE/EIA 1999).

The realization of any savings in the residential sector is a function of the pattern of energy utilization in the household. When we compare expenditures by end-use, we find that as much as two thirds of energy-related expenditures are for the principal end uses of space conditioning, water heating and refrigeration (see Figure 4.3). Consider these end-uses to be essential energy services since they are shared across all income classes. The nationwide average expenditures per household for these services was $714 in 1997 for households with incomes less than $10,000, and $863 for households with incomes between $25,000 and $49,999 (DOE/EIA 1999): a 20 percent increase for a three-to-five-times greater household income. Savings, therefore, in essential energy services will be far more beneficial from a monetary standpoint to the low-income household than to other households. The comfort and utility derived from essential energy services will be much more sensitive to energy price and equipment efficiency for low-income households than for other households. For these reasons, for the remainder of this chapter, we focus upon residential energy efficiency as it applies to low-income households.

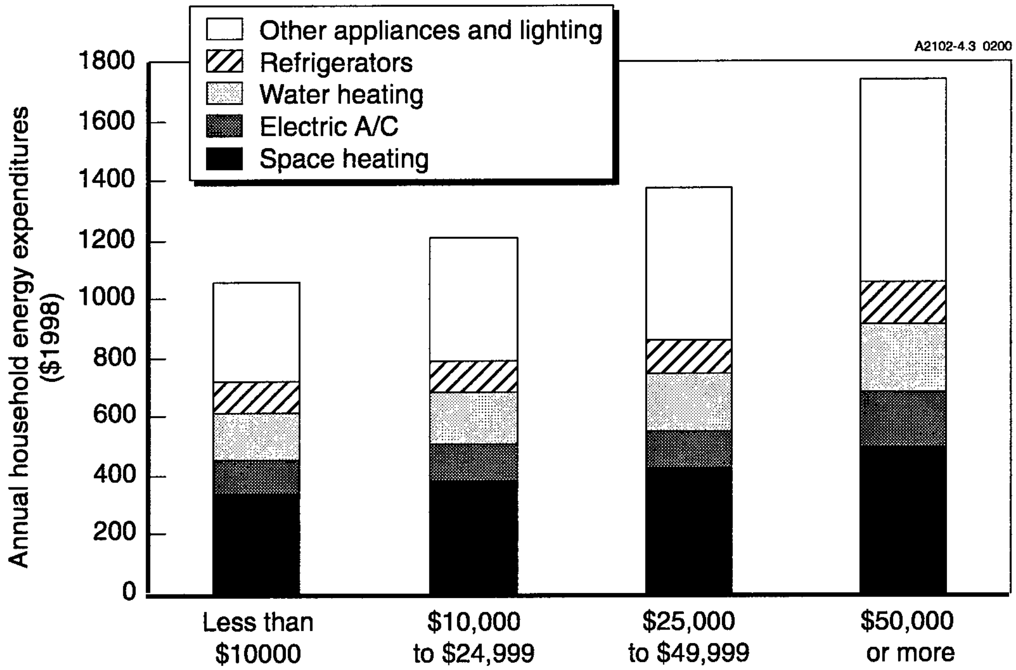

Figure 4.3. Annual energy expenditures by end use and household income (DOE/EIA 1999).

While residential energy efficiency improvements provide benefits to all households, low-income households[6] are especially sensitive to energy costs, and so the benefits are more significant. It is widely recognized that low-income households spend a large part of their income on energy expenses; estimates include:

- More than thirty percent (Megdal and Piper 1994).
- Three to seven times the fraction spent by a median income household (Pye 1996).
- Twenty-two percent of income versus five percent by a median income household (Colton 1993).

[6] Various definitions of "low income" are employed in the literature, e.g., less than 150% of the federal poverty line, less than 60% of the state median household income, or eligibility for various public assistance programs. Some studies use operational definitions, such as energy expenses as a percentage of income, available resources to pay energy bills (after other necessary household expenses), or persistent arrears and service terminations. Roger D. Colton, 1993, "Methods of measuring energy needs of the poor: An introduction," Belmont, Mass.: Fisher, Sheehan & Colton. While the criterion used clearly influences the resulting figures, qualitative results are generally independent of the particular low-income measure; when the criterion is important, it will be noted.

- Eight percent of income spent on electricity (twenty-three percent for the very poor—below fifty percent of the federal poverty level), compared with two percent by a median income household (Howat and Oppenheim 1999).

The energy burden borne by these households is exacerbated by their relatively inefficient use of energy; the housing stock occupied by low-income households tends to be older than the average, and therefore designed and built in a less energy efficient manner and equipped with less energy efficient fixtures and appliances. A study of low-income households found that 64 percent of households with less than $5000 annual income have ceiling insulation, compared with 91 percent of households with more than $50,000 annual income, and that fourteen percent of the former group versus five percent of the latter group have a more than twenty-year old refrigerator (Chandrasekar et. al 1994). Among residences heated primarily with natural gas, those built since 1980 use forty-three percent less energy than those built between 1940 and 1979 (DOE/EIA 1995).[7] More generally, the average 1700 sq. ft. house in California built before 1977 and not improved since requires $2700 annually to heat and cool, while the same size house built to current standards requires only $700.

Circumstances in California differ somewhat from the national picture. While twenty-three percent of the state's population lives in households below 150% of the federal poverty level (Olds 1996)—the ninth highest rate[8]—much of the low-income population lives in the moderate climate coastal zones, and in relatively newer housing than elsewhere in the country, with concomitantly less need for heating and cooling than the national average. Nonetheless, a significant portion of the low-income population does live in interior regions with significant heating and cooling needs, and energy prices in California are among the highest in the nation. California's rural households face especially large energy burdens, as they tend to live in more extreme climates, have limited natural gas service and so must rely on less efficient electric heating, and must

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[7] Energy use is normalized as cubic feet natural gas per heating degree day per square foot floor space.

[8] Bureau of the Census, www.census.gov/hhes/poverty/poverty98/pv98state.html (accessed January 9, 2000). The federal poverty level is not adjusted for local cost of living, which would rank California even higher; a 1998 study by Ernst and Young shows that San Francisco, Los Angeles, Oakland, and San Jose rank numbers two, three, five, and nine, respectively, among the least affordable housing markets in the country http://www.ey.com/industry/realestate/housingstudy.asp (accessed January 9, 2000).

use electricity for services such as water pumping and outdoor lighting that are provided by municipalities in urban areas.[9]

Relative energy burdens on low-income households in California are large: Low-income households (below 150% of the federal poverty level) spend ten percent of their income on energy, whereas median-income households spend three percent of their income on energy. These expenditures are not uniform throughout the year. For example, summertime electric bills are approximately twenty percent of income for California low-income households (NCLC 1995).[10]

In California, the typical low-income household (below 100% of the federal poverty level) spends $525 per year on electricity (Colton 1994), compared with an average for median- income households of $705; for natural gas the expenditures are $286 and $316 respectively (DOE/EIA 1995). Energy expenditures are broken down by end use in Table 4.2.

Table 4.2[11] Annual household energy expenditure by end use ($1993).

Income level	Space heating	Air-conditioning	Water heating	Refrigeration	Appliances
Low-income	163	88	162	92	351
Median-income	193	137	138	139	519

We see that the typical low-income household spends nearly as much on space heating as does the typical median-income household, despite having much smaller residences, due to the less energy efficient construction and heating equipment in low-income residences[12]. The figures for water heating are even more striking, with low-income households spending more than median-income households, due to a number of factors, including greater reliance on inefficient electric heating, lack of dishwashers, age

[9] See California Energy Commission, 1998, "What electricity restructuring means for rural California counties," P300-98-011.
[10] 1995, "Energy and the Poor: The Crisis Continues," Washington, D.C.: National Consumer Law Center.
[11] Note that the end use expenditures do not sum to the totals by fuel noted elsewhere in the text, as slightly different populations are used in the different surveys; the discrepancies are small and do not alter the interpretations.
[12] For residences with electric primary space heating, low-income households average 881 sq. ft. versus 1425 sq. ft. for median income households; for natural gas heating, the averages are 1095 sq. ft. and 1541

of plumbing and appliances. Low-income households constitute twenty percent of those with electric water heating (spending an average of $224 annually), and fourteen percent of those with gas heating (spending $142).

In recognition of these energy burdens, numerous federal, state, and utility administered programs have sought to reduce energy costs, by direct financial assistance and by energy efficiency programs. The Federal Weatherization Assistance Program (WAP) was established in 1974 under the Community Services Act, to reduce the cost of heating and cooling by improving building energy efficiency. The Low-Income Home Energy Assistance Program (LIHEAP), administered by the Department of Health and Human Services, was established in 1980 to reduce the burden of energy costs, to improve health, safety, and comfort; and to prevent termination of energy services.[13] Many of these programs have been shown to be cost effective (Pye 1996).

California's Low-Income Energy Efficiency (LIEE) program grew out of federally funded weatherization programs begun in 1976, administered by the Department of Community Services and Development, which contracted with community based organizations. Utility-sponsored weatherization programs began in 1982 for San Diego Gas & Electric, 1983 for Pacific Gas & Electric and Southern California Gas, and 1984 for Southern California Edison. These original programs installed six basic weatherization measures: (1) attic insulation, (2) caulking, (3) weather stripping, (4) low flow showerheads, (5) water heater blankets, and (6) duct wrap.[14] By 1994 the roster of services provided had grown considerably, to include energy efficient appliances and energy education programs.

The cost savings to low-income families from energy efficiency measures can be substantial. While a full cost-effectiveness analysis of low-income energy efficiency

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sq. ft., respectively. For both heating types, the average number of heating degree-days is nearly equal for low- and median- income households

[13] Funding for LIHEAP has been in steep decline, from $1.8 billion in 1987 to $1.1 billion in 1999; perhaps not coincidentally, the number of service terminations has doubled since 1988 (Pye 1996). LIHEAP provides block grants to the states and other administrative bodies, which apply their own selection criteria within federal guidelines. The program is widely seen as favoring "heating degree days" over "cooling degree days," and therefore northeastern over southwestern states; the FY98 LIHEAP allocation to California was $45 per taxpayer, while the cost burden was $120; Glenn R. Schleede, 1998, "Pull the Plug on Federal Funding for LIHEAP," Policy Paper No. 103, Alexandria, Vir.: National Taxpayers Union Foundation.

programs in California is beyond the scope of this report, some prior findings are instructive, even as the Low Income Governing Board (LIGB) has noted that:

> The CPUC has recognized that in the case of energy efficiency programs serving the low-income customers there are important considerations that are difficult to quantify in dollar terms, but which should nonetheless be included in a determination of program design and measure selection. In light of that, the CPUC has not required that low-income energy efficiency programs meet standard cost-effectiveness tests.[15]

A 1997 metaevaluation of numerous state weatherization programs under WAP showed that benefit-cost ratios increased on the order of 80 percent between 1989 and 1996, due to more complete audits and better and more effectively targeted improvements (Berry, Brown and Kinney 1997). Various perspectives of benefits were employed, from one-year savings on energy bills to twenty-year returns on societal benefits; in 1996 the average benefit-cost ratio for first year energy savings was 1.79. In the study, Northern California was included in the "moderate" climate region, and Southern California in the "warm region;" Table 4.3 shows the average reductions in home energy costs for households in the two regions after weatherization. Average benefit-cost ratios, depending on the perspective, were 1.2 to 2.7 for moderate climate programs, and 0.4 to 1.6 for warm climates.

Table 4.3. First-year reduction in home energy costs (ORNL 1997).

	Electricity		Natural gas	
Climate	Space heating	Total	Space heating	Total
"Moderate" climate	44%	15%	18%	12%
"Warm" climate	16%	5%	15%	11%

A detailed study of low-income weatherization programs nationwide found that, in general, the more that is invested in weatherizing a dwelling, the greater the savings (Berry and Brown 1996). More specifically, savings were found to be linear with costs over the entire range of the data, with no evidence of diminishing returns. Aside from weatherization, other low-income energy efficiency measures include compact fluorescent bulbs, which use seventy percent less energy than incandescent bulbs; and

[14] These measures were mandated under SB 845 (1989).
[15] See document at http://www.ligb.org/docs/Master%20rework-J.doc.

refrigerator replacement, which can lower electric bills by five hundred to one thousand dollars over the unit's lifetime.

As the low-income housing stock is relatively less energy efficient than that of other income levels, the gains to be had are potentially greater. Figure 4.4 shows the energy burden on California households, and the possible influences of demographic changes (see Section 2.2, page 7) and energy efficiency improvements; Figure 4.5 shows the absolute energy expenditures, and the possible influences. As housing prices in temperate climate zones increase, low-income households may be driven to areas that require increased cooling and heating which would increase the energy burden of low-income households to a greater degree than for other households. The upper shadow in Figure 4.4 and Figure 4.5 illustrates the potential magnitude of the shift. Likewise, energy efficiency improvements to low-income households have the potential to reduce the energy burden. The lower shadow in Figure 4.4 and Figure 4.5 illustrates the possible reduction in the energy burden for low-income households.

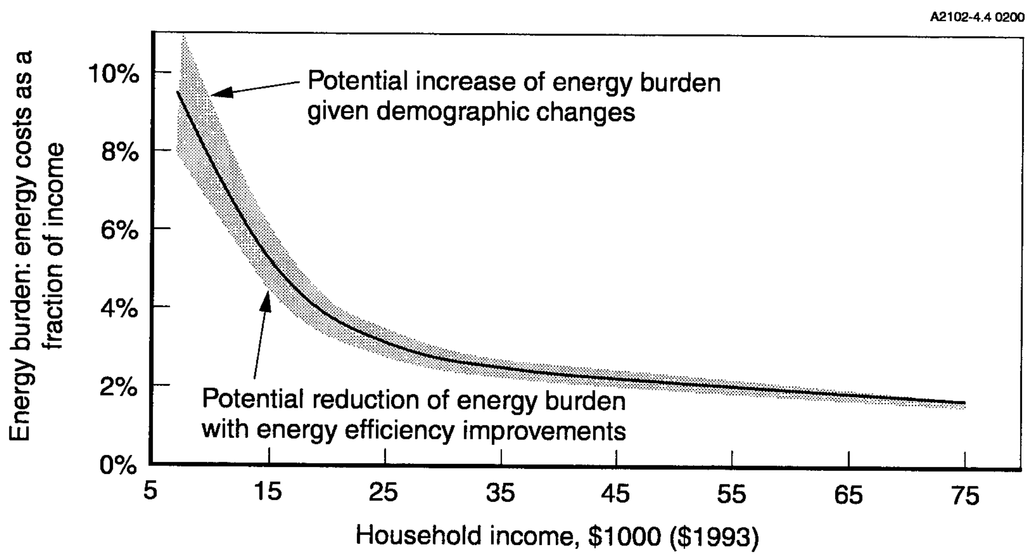

Figure 4.4. California household energy expenditure as a percentage of income (EIA 1997).

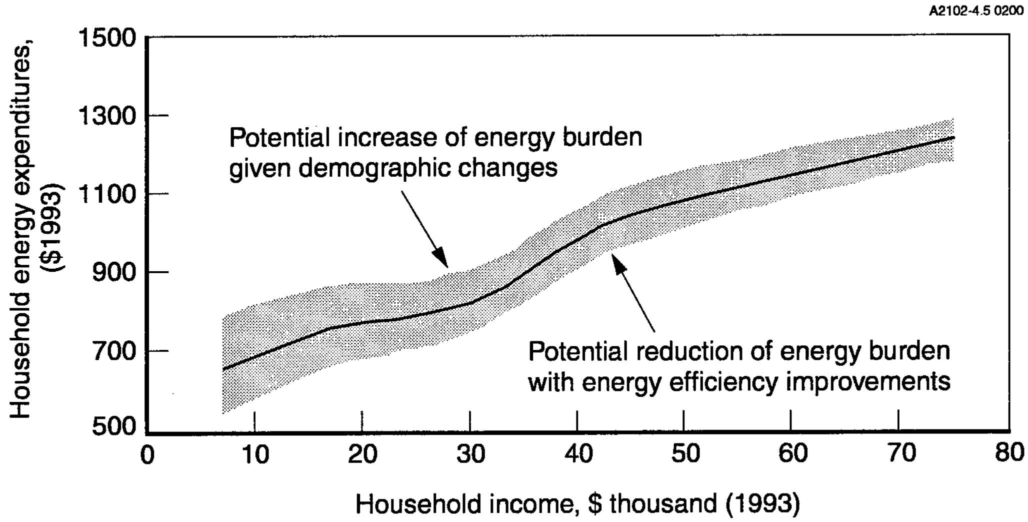

Figure 4.5. California household energy expenditure (EIA 1997).

For a given level of heating, cooling, lighting or appliance usage, the more efficient the device the less the expenditure on energy. In this respect, low-income households benefit from having more disposable income, as do all households. But low-income households derive a broader set of benefits from a reduced energy burden, and benefits from greater energy efficiency for low-income households rebound to society as well.[16]

The broader benefits to households include increased comfort and health,[17] safety,[18] reduced loss of service from termination, and increased housing development and property values.[19] Some of the cost savings from energy efficiency may be "taken back" in increased usage;[20] for example, if a residence is better insulated so as to increase the energy efficiency of air conditioning, the household may spend the same amount as previously on air conditioning, but have more comfort.

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[16] A national survey of weatherization program participants found $976 in annual benefits per weatherized household (Brown, Berry and Kinney 1994).

[17] In the ORNL survey, respondents uniformly cited improved comfort and health after weatherization (Brown, Berry, Kinney 1994). Another study found an average of 1150 hot-weather related indoor deaths per summer, over an eleven-year period (Pye 1996).

[18] Older and less efficient appliances tend to be less safe, as well, as with natural gas appliances that emit carbon monoxide.

[19] These improvements are of direct benefit only to those low-income households that own their residences.

[20] Takeback is generally included as a benefit in cost-effectiveness evaluations (EPRI).

The benefits to society and to utilities include reduced arrearages, and other transaction costs; reduced public expenditures (including health, fire, building inspection, unemployment insurance, homeless shelters, and housing programs, see Howat and Oppenheim (1999); and an improved local economy, as low-income households tend to spend their discretionary dollars locally, while most energy expenditures are transferred outside the community (Howat and Oppenheim 1999).

5 Conclusions

Changes in energy efficiency – as measured by independent changes in energy intensity – have had significant economic benefits for California; it is also possible that the benefits will continue into the future. These benefits did occur in the presence of investment on the part of the government, the private sector, and state residents. However, we have shown no specific link between energy efficiency programs and the improvements in energy efficiency in the state.

The economic potential for energy savings is significant. Past evaluations of energy efficiency programs indicate that the programs can be directly responsible for energy savings. We have shown that claimed savings energy efficiency programs in the industrial and commercial sectors have provided a positive return on the state investment under the assumptions. Future programs that have similar success rates as their predecessors would likely result in economic benefits for the state.

In addition, we argue that the benefits of energy efficiency for California households – low-income households in particular – are great. Energy efficiency programs targeted to the low-income residential consumer are unique among government programs: They directly increase both net income and quality of life.

The future of energy consumption, prices, and intensity in California is uncertain. Restructuring in the retail and wholesale energy industry may increase energy services and reduce prices thus providing consumers with fewer incentives to improve energy efficiency. The analysis here indicates that greater energy efficiency has a positive effect on the California economy and that targeted energy efficiency programs in all sectors have the potential to provide significant benefits to the state.

RAND

MR-1212.0-CEC

A Excerpts of relative legislation

A.1 AB 1105, Amended in Senate, 15 June 1999

(28) Existing law establishes the State Energy Resources Conservation and Development Commission in the Resources Agency, and specifies the powers and duties of the commission.

This bill would require the commission to conduct a public process to prepare a transition plan report and an operational plan report concerning the transfer of energy efficiency programs from the Public Utilities Commission to the State Energy Resources Conservation and Development Commission, and to submit these reports to the Legislature by January 1, 2000.

SEC. 44. (a) The State Energy Resources Conservation and Development Commission shall conduct a public process to prepare a transition plan report on the transfer of energy efficiency programs from the Public Utilities Commission to the State Energy Resources Conservation and Development Commission, and, notwithstanding Section 7550.5 of the Government Code, submit that report to the Legislature by January 1, 2000. For that purpose, the transition is defined as the period through December 31, 2001, during which utilities will continue as primary program administrators under the oversight of the Public Utilities Commission. The transition plan shall include consideration of all of the following:

(1) Issues associated with oversight responsibility, including those associated with the transfer of responsibility from the Public Utilities Commission to the State Energy Resources Conservation and Development Commission.

(2) Implementation and sequencing issues associated with the transfer of responsibility for administration of energy efficiency activities from utilities to a new administrative structure.

(3) Coordination and synergy between this program and the other public goods charge programs such as the Public Interest Energy Research (PIER) program.

(4) Program requirements necessary to ensure that current programs apply market transformation principles and result in sustainable cost-beneficial improvements in California's energy markets.

(5) Resources necessary to implement that transition plan.

(b) The State Energy Resources Conservation and Development Commission shall conduct a public process to prepare an operation plan report and, notwithstanding Section 7550.5 of the Government Code, submit that report to the Legislature by January 1, 2000. The operational plan report shall recommend a post transition administrative structure that is designed to achieve efficient and effective program administration. The report shall consider all of the following:

(1) The application of market transformation principles to achieve cost-effective energy efficiency and conservation through sustainable, cost-beneficial improvements in California's energy markets.

(2) Assessment of energy markets to identify feasible ways of improving market structures, including, but not necessarily limited to, an assessment of California's untapped opportunities to secure cost-effective savings.

(3) Programs that result in sustainable improvements in the information environment, market rules, and other aspects of market structures that result in either of the following:

(A) Enabling private businesses to innovate and provide energy efficient products and services.

(B) Supporting the ability of customers to make more intelligent energy choices.

(4) The appropriate roles of other private and public entities providing energy efficiency services, including, but not limited to, designating a public benefit, nonprofit corporation as the program administrator.

(5) Whether eligibility for programs funds should be expanded to support the ability of electricity consumers to shift electricity usage in response to pricing differences.

(6) The appropriate funding levels for energy efficiency and conservation in the post-2001 period and appropriate program oversight in the post-2001 period.

(7) Minimizing the role of state agencies in providing administrative and implementation services.

(8) Programs in existing residential and nonresidential program areas that reduce consumer energy bills while stimulating the growth of a competitive industry providing cost-effective products and services, such as the Standard Performance Contract program.

A.2 Item 3360-001-0465 of Governor Davis' budget comments on AB 1105

I am sustaining Provisions 1 and 2, which requires the Energy Resources, Conservation and Development Commission to evaluate the efficacy of the State's Renewable Energy Resource Program. I am also sustaining Provision 5, which requires the Commission to prepare a plan regarding the post-transition administrative structure to achieve cost-effective energy efficiency and conservation in the State's energy markets. I believe that both reports will be useful. However, the reporting requirement outlined in these provisions fall short of providing a complete, objective assessment of the affected programs. The provisions prejudge the evaluations by assuming program continuation without first providing consideration for whether there is a need for the programs. Additionally, the provisions do not provide for adequate independent review to ensure the studies are valid, reliable, statistically sound, and based on performance measures. Therefore, I am directing the California Energy Commission to include these factors in the evaluations.

RAND

MR-1212.0-CEC

B Quantitative Methodology

While intuitively it seems easy to argue that improvements in industrial and commercial energy efficiency have economic benefits, quantifying this relationship at an aggregate level is a complex undertaking.[21] Perhaps the greatest difficulty in estimating such a relationship is in measuring energy efficiency, in both a theoretical and practical sense. Consequently, it will be useful first to develop a theoretical framework in which to define precisely what we mean by energy efficiency and then to understand how energy efficiency as such affects economic growth. The theory developed in Section B.1 subsequently guides the development of an empirical specification in Section B.2 and helps us to interpret the results presented in Sections B.3 and B.4.

B.1 Theory

Improvement in energy efficiency is one form of technological progress, which most researchers agree has been an important source of economic growth throughout history. Economists typically think of technological progress in the following way. Suppose the economy produces output, Q, at time, t, using three inputs, capital, K, labor, L, and energy, E, according to the following production function:

$$Q_t = F(K_t, L_t, E_t) \tag{1}$$

One way to represent this production function is in terms of its isoquants. An isoquant tells us all the different combinations of inputs that will yield some fixed level of output. In Figure B.1, the combination of K_3 units of capital and E_3 units of energy produces the same level of output as K_4 units of capital and E_2 units of energy, namely Q_o^t (we hold labor constant). Now suppose there is some technological advance in the next period, $t+1$. We can represent this advance in Figure B.1 by the isoquant labeled Q_o^{t+1}. Previously, if we wanted to produce Q_o using K_3 units of capital we needed E_3 units of energy, whereas now we need only E_1 units of energy. Thus, we can assume technology

[21] For the purposes of this section, energy efficiency refers to industrial and commercial energy efficiency only. See Chapter 4 for a discussion of residential energy efficiency.

has advanced if, holding all other inputs constant, it takes less energy to produce a given level of output than before.

From an empirical standpoint, we are interested in three aspects of this shift in the isoquant: 1) the magnitude of the overall shift, 2) the degree to which this shift can be attributed to particular factors of production, and 3) how this shift affects economic growth. A common proxy for this shift in isoquants is the ratio of inputs to outputs, or factor intensity, X/Q, where X is some input. But even our simple analysis thus far tells us right away that we must be cautious in how we interpret such a ratio. Suppose, for example, we wish to use energy intensity, E/Q, as a measure of energy efficiency. As the economy moves from Q_o^t to Q_o^{t+1}, E/Q_o will fall for any given level of capital and labor. But note that if we fail to hold other inputs fixed, a fall in E/Q_o is also consistent with northwesterly movements along the isoquant Q_o^t where technological progress remains constant.

Missing from this analysis, of course, is any notion of firm behavior. The standard economic theory of the firm tells us that firms minimize the cost of production by choosing inputs so that the marginal product of any input is just equal to its price. Given some price level P^e/P^k, this corresponds to choosing the combination K_3, E_3 on isoquant Q_o^t and the combination K_2, E_2 on isoquant Q_o^{t+1}. Note that if the price of energy were to decrease between periods t and $t+1$, the firm might choose to produce at the point K_1, E_4 leading to a rise in E/Q_o even though there was a technological advance. Clearly, then it will be important to hold relative prices constant if we are to interpret a decline in energy intensity as an indication of technological progress.

Holding prices constant, though, may not be enough if technological progress is not neutral with respect to all inputs. That is, it may be that technological progress augments the productivity of one input more than others. For example, a rise in thermal efficiency makes energy more productive, but leaves capital and labor productivity relatively constant. This is represented in Figure B.2, where the isoquant has shifted disproportionately between periods t and $t+1$. For a given level of prices, firms will choose to use more energy given isoquant Q_o^t than given isoquant Q_o^{t+1}, despite the improvement in energy efficiency. What this amounts to saying is that in addition to

prices, we need to hold input shares constant as well. Note also that this analysis implicitly assumes that the type of output produced remains constant. If a firm or economy shifts to producing a different set of goods using less energy in the process, it is not at all clear that this fall in energy intensity reflects technological change.

Now let us consider how energy efficiency, and technology in general, affects economic growth. One way to do this is to augment the production function in (1) with an explicit technology parameter, A_t:

$$Q_t = A_t F(\mathbf{X}_t) \tag{2}$$

where $\mathbf{X}_t$ is a vector of inputs. A_t is typically referred to as total factor productivity (TFP). It is not difficult to show that the growth rate in TFP can be expressed as the difference between the growth rate of output and the sum of the growth rates of all inputs weighted by their share in production:

$$\dot{A}/A = \dot{Q}/Q - \sum \alpha_i \dot{\mathbf{X}}_i / \mathbf{X} \tag{3}$$

where, under constant returns to scale, α_i represents the factor share and the dot notation indicates a time derivative. Thus, the rate of change in TFP is measured as a residual.[22] The contribution of TFP to total economic growth varies substantially over time and across regions. In the United States, it is estimated that growth in TFP accounted for over one third of the growth in gross domestic product (GDP) between 1947-73. The contribution of TFP to GDP growth was considerably lower, about 13 percent, between 1960-90 (Barro and Sala-i-Martin 1995). While this growth accounting framework has been used extensively in making comparisons of productivity across nations, states, industries, and time, the method does not provide a real explanation for growth in output; (3) tells us nothing about why the growth rate of output has exceeded the growth rate in inputs. For this reason, economists have often referred to TFP as a "measure of our ignorance" (Jorgenson and Griliches 1967).[23]

Given the importance of TFP, it is not surprising that a large body of research has aimed at explaining its change over time. There is some agreement that much of its variation reflects changes in the composition of inputs that can be masked by aggregation

[22] We model technology here as factor-neutral for ease of exposition.
[23] Alternatively, this term is sometimes called the Solow residual after Solow (1957).

(Jorgenson and Griliches 1967). The proportion of the workforce with a college education, for example, has risen steadily over time and this presumably has had a positive impact on economic growth. Similarly, much of this residual can be explained by the gradual adoption of new technology embodied in new capital. Productive efficiency, then, is a function of not only the availability of new technology, but also the feasibility of its adoption. The degree to which we can interpret this residual as productivity also depends on how successful we are at measuring output. If the analysis does not hold the composition of output constant, something that is very difficult to do, then the residual might simply reflect movements away from the production of energy-intensive goods rather than a gain in efficiency per se.

Assuming we could measure TFP properly, we would like to be able to decompose its change between any two years into changes in individual factor productivities. It would then be a simple task to assign fractions of the total change in economic growth to changes in particular factor productivities. There are many complications in performing such a decomposition, however, and to our knowledge no attempt has been made to do so in the extensive literature on TFP. The basic problem is that technical change is not exogenous. Technical change comes about from the effort of scientists, engineers, and entrepreneurs who, in response to economic incentives, make important innovations that shift the economy's production possibilities frontier outward (Griliches 1998). Moreover, technical change is not necessarily something that you can assign to a particular factor of production. This is particularly true of energy, which is so integral to production yet represents such a minor share of total production costs.

Widespread electrification in the early part of this century is a good case in point. Electric motors as a percentage of total horse power increased from 25 percent in 1910 to 90 percent in 1939 (Schurr 1983). Schurr (1983) writes "… with the use of electric motors, which could be flexibly mounted on individual machines, the sequence and layout of productive operations within the factory could be made to match the underlying logic of the productive process, as opposed to the more constrained organization of production imposed by a system of shafts and belting linked to a single prime mover." Thus, not only did electricity provide a more efficient form of energy delivery, it sparked a revolution in the organization of production that surely has led to higher levels of

growth. Similarly, the availability of new fuels in metallurgy not only decreased energy costs but, according to Rosenberg (1983), brought forth efficiency improvements throughout the production process.

This suggests that we need to think of the economic benefits of energy efficiency in a broad context. It may not be the case that optimizing over thermal efficiency alone is economically efficient. It may make sense to employ highly energy-intensive technologies in some sectors in order to improve efficiency in other sectors. For example, pelletization of low-grade ores in the mining process increased energy intensity in the mining sector, but drastically reduced energy intensity in the metallurgy sector. While aluminum requires the use of a highly electricity-intensive process, aluminum itself has improved energy efficiency in many industries. Qualitative changes in inputs can set off chain reactions that may affect many inputs and outputs both within and outside the sector in which this change occurred (Rosenberg 1983).

As one might imagine, then, it is difficult to capture the dynamic effects of innovations in energy technology on economic growth in a single measure. For example, it is not clear that some index of thermal efficiency, even if data existed to construct such a thing for an entire economy, would truly capture everything we mean by improvements in energy efficiency. Barro and Sala-i-Martin (1995) point out that the growth rate of inputs in general is endogenous in the sense that it is driven by technological progress. Technological progress, then, also has an indirect effect on output by driving growth of inputs, something that is not captured in TFP.

Our approach, which is largely dictated by data constraints, will be to use energy intensity as a measure of energy efficiency in a reduced-form regression analysis. We will be asking, how do changes in energy intensity affect economic growth? It is our hope that this relationship in the presence of controls for the measurable determinants of energy intensity will approximate the relationship between energy efficiency and economic growth. Due to the complex interplay of energy, capital, and technological progress in general, however, we should exercise caution in interpreting our results.

B.2 Empirical Specification

Our empirical strategy involves the use of panel data on energy consumption and gross state product for 48 states (we exclude Alaska, Hawaii, and the District of Columbia) for the years 1977-1995. The use of panel data provides us with far more variation with which to identify the impact of energy intensity on economic growth than if we were to employ a single time series for the United States as a whole or a given state. While it is entirely possible that energy intensity could have different effects on economic growth in different states, we believe this is a relatively minor disadvantage compared to the advantages of using panel data in this case. In section B.4 we consider how to apply these national estimates to data for California alone.

The energy intensity of the U.S. economy has declined steadily, with few exceptions, since the early 1920s (Schurr and Netschert 1960; Berndt and Wood 1974). Table B.1 presents energy intensity figures for the United States and California. As can be seen, industrial energy intensity declined by approximately 22 percent and commercial energy intensity by 28 percent between 1977 and 1995.[24] California's economy both is less energy intensive than that of the United States on average and experienced a larger percentage decline in energy intensity over the same period (a decline of 36 percent in industrial energy intensity and 48 percent in commercial energy intensity). Figure B.3 maps the decline in log industrial and commercial energy intensity in the United States over the same period. Differences in logs can be interpreted as approximate percentage changes. While these aggregate trends mask some of the sectoral and regional variation in energy intensity over time, the overall trend in the United States is unambiguously toward lower energy intensity.

Theory tells us that energy intensity should be a function of relative prices. Energy demand should fall as energy prices rise relative to other inputs. The magnitude of this price response will depend on the degree to which firms can substitute between inputs both in the short and long runs.[25] Aggregate energy intensity measures, like those

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[24] For the purposes of this report, the industrial sector includes SICs 10000-50000 and the commercial sector includes SICs 70000-100000.

[25] There is a great deal of empirical research into the price elasticity of energy demand and whether energy and capital are in fact substitutes or complements in production. See, for example, Solow (1987).

we use in this study, will also be a function of the composition of output. If the economy shifts toward the production of paper and chemicals, for example, we might expect aggregate energy intensity to increase. A rise in energy intensity in this case does not mean that the economy has become less efficient, but simply that the economy is producing more energy-intensive products. We might imagine that many other factors will also influence energy intensity like the age of the capital stock, climate, and energy policy. Thus, energy intensity is likely to be a noisy indicator of what we might be most interested in measuring; namely, changes in production methods and the introduction of more energy efficient technology.

To see this, consider the following regression specification:

$$EI_{it} = \beta_1 P_{it}^e + \beta_2 EM_{it} + \beta_3 K_{it} + \beta_4 C_{it} + \lambda_i + v_t + \varepsilon_{it} \tag{4}$$

where i indexes states, t indexes time, and the variables are all in log form and defined as follows:

EI	Energy intensity in the industrial sector taking the form E_{it}/Y_{it}, where E is energy consumption and Y represents industrial output (10^3 Btu/\$).[26]
P^e	Real energy prices in the industrial sector (\$/10^6 Btu).
EM	Proportion of industrial output accounted for by energy-intensive manufacturing. In the regression results below I allow non-mining manufacturing intensity (*Manufacturing*) and mining-intensity (*Mining*) to have separate effects.[27]
K	New capital expenditures (buildings and equipment) in the industrial sector (\$$10^6$)
C	An index of heating and cooling days.
λ	A state fixed effect.
v	A time fixed effect.

We would expect real energy prices to enter negatively and industrial composition, new capital expenditures, and the climate index to enter positively (i.e., $\hat{\beta}_1 < 0$, and $\hat{\beta}_2, \hat{\beta}_3, \hat{\beta}_4 > 0$). The relative price term could be formulated to include lagged prices as well under the assumption that substitutions between energy and other inputs do not occur instantaneously. The error term in this regression allows for individual state and year effects (λ_i and v_t) and an idiosyncratic error term η_{it}. The sum of λ_i, v_t, and η_{it} provides us with a measure of changes in energy consumption by state and

[26] All economic variables are deflated using the producer price index with base year 1982.
[27] Energy-intensive manufacturing industries include mining (30000), stone, clay, and glass (51320), primary metals (51330), paper products (52260), chemicals (52280), and petroleum products (52290).

year that are not due to prices, industrial composition, and other covariates. This error term has been referred to elsewhere as autonomous energy efficiency (AEE) (Dowlatabadi and Oravetz 1997).

We can formulate a similar regression for the commercial sector. The composition of commercial output, however, is unlikely to be a factor in predicting state commercial energy intensity and so we exclude such a measure from the regression. New capital expenditures here represent investment in new buildings (expressed in square footage) under the assumption that new buildings are more likely to incorporate energy efficient technology than old buildings. Unfortunately, we have no data on new capital expenditures on equipment in the commercial sector.

Table B.2 presents regression results for the industrial and commercial sectors. As expected, the price and new capital terms enter negatively and the industrial composition and climate terms enter positively. Surprisingly, though, the price response of commercial energy intensity is quite small in magnitude and not statistically significant. Climate appears to have a stronger effect on commercial energy intensity than on industrial energy intensity. The large difference in response between industrial and commercial sectors to expenditures on new capital is due to the fact that capital expenditures is measured as a flow for industrial establishments (*New capital*) and a stock for commercial establishments (*Building*).[28] With the inclusion of state fixed effects the coefficient β_3 represents the effect of deviations from within-state mean new industrial capital flows on industrial energy intensity and deviations from the within-state mean commercial building stocks on commercial energy intensity. It is not surprising that changes in the flow of new capital has a smaller effect than changes in the stock of new capital on energy intensity, since flows generally have much smaller variances than stocks.

Together, the included covariates explain about one third of the variation in energy intensity observed in the data. State and year effects explain much of the remaining variation, roughly 55 percent. The state effects alone capture permanent differences across states in energy intensity, perhaps driven by differences in energy

policies, geography, and economic conditions. Year effects capture differences in energy intensity across years that are not attributable to changes in energy prices, shifts in the economy away from heavily energy intensive manufacturing sectors, and the installation of new capital and construction of new buildings. The idiosyncratic error term, η_{it}, represents the remaining variation in energy intensity specific to each state and time interaction. Figure B.4 graphs the sum of the year effects and idiosyncratic errors over time. As can be seen, this residual term increases between 1977 and 1982 and then declines thereafter. Thus, net of price and other behavioral influences, industrial and commercial establishments appear to have become more energy intensive during the early 1980s and then progressively less energy intensive over the remaining 13 years in the data.

It could be argued that the change in this residual term captures changes in energy efficiency since we have controlled for the firm's response to price and other influences. This would imply that industrial and commercial establishments became less energy efficient during the early 1980s and then increasingly energy efficient from that point forward. In truth, though, the residual captures variation in all variables omitted from the model and so, by definition, we do not know with certainty what it represents. The year effects are common shocks to energy intensity across states. Whether those shocks are related to advances in technology is unclear. The year effects could be picking up systematic measurement error as well. It is also possible that the other covariates in the model are picking up changes in technology themselves. For example, firms might respond to increases in energy prices not only by substituting away from energy toward other inputs but also by investing in research and development of more energy efficient technologies. In our judgment, then, this residual is not a satisfactory proxy for energy efficiency.

Our approach is to use energy intensity directly as a proxy for energy efficiency. Thus, in the analysis to follow we interpret the effect of changes in energy intensity on economic growth as the effect of changes in energy efficiency on economic growth. The evidence in Table B.2 tells us, though, that variation in energy intensity reflects variation

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[28] The U.S. government does not keep track of capital stock. Other estimates in the literature (e.g., Holtz-

in prices and additional factors other than energy efficiency and so we must control for the independent effect these factors might have on economic growth. If energy prices and other variables that have independent effects on both energy intensity and economic growth are omitted from the model, then we risk attributing the effect these variables have on economic growth to energy intensity. To be concrete, consider the following model of gross state product (GSP):

$$\begin{aligned}\Delta_t \ln GSP_{it} = \alpha_0 + \Delta_{t-1} \ln EI_i \alpha_1 + \Delta_{t-1} \ln P_i^e \alpha_2 + \Delta_{t-1} \ln EM_i \alpha_3 + \Delta_{t-1} \ln K_i \alpha_4 + \\ \Delta_{t-1} \ln C_i \alpha_5 + \Delta_t \ln X_i \alpha_6 + \lambda_i + v_t + \varepsilon_{it}\end{aligned} \tag{5}$$

where Δ_t denotes first differences between periods t and t-1 (e.g., $\Delta_t \ln GSP_{it} = \ln GSP_{i,t} - \ln GSP_{i,t-1}$) and Δ_{t-1} denotes first differences between periods t-1 and t-2. The variables in the model are defined as follows:

GSP Per capita gross state product ($\$10^6$).
EI A vector of energy intensity variables taking the form E_{ijt}/Y_{ijt}, where E_j represents the energy consumption in sector j (industrial, commercial, and transportation) in Btus and Y_j represents the output of that sector (10^3 Btus/\$).
P^e A vector of real energy prices in the industrial, commercial, and transportation sectors ($\$/10^6$).
EM Proportion of industrial output accounted for by energy-intensive manufacturing (*Manufacturing* and *Mining*).
K A vector of new capital expenditures in the industrial sector (*New capital*, $\$10^6$) and stock of commercial building square footage (*Building*, ft^2).
C An index of heating and cooling days.
X A vector of additional covariates typically included in cross-state growth regressions—proportion of the population of working age (18-65), proportion of the population with a college-level education or more, service share of output, and government expenditures as a fraction of total output.
λ A state fixed effect.
v A time fixed effect.

This specification follows a large literature on the determinants of economic growth.[29] It argues that per capita state economic growth is correlated with both the stock and flow of capital and labor, their quality, and governmental policies. The inclusion of state fixed effects accounts for differences in initial economic conditions and

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Eakin 1993) do not cover our sample period adequately.

[29] Standard references include Solow (1957), Dennison (1962), Barro and Sala-i-Martin (1995), Griliches (1998), and Jorgenson, Gollop, and Fraumeni (1987). See Crain and Lee (1999) for a review of the empirical literature on the determinants of U.S. state economic growth.

governmental policies (separate from expenditures) that affect economic growth. Time fixed effects control for business cycle effects common to all states.

The estimated coefficients on EI_i provide us with an estimate of the effect of changes in the growth rate of energy intensity on the rate of state economic growth. A value of $\hat{\alpha}_1$ of –0.10, for example, says that an increase in the rate of growth in energy intensity between periods *t-2* and *t-1* of ten percentage points, *holding energy prices, industrial composition, new capital expenditures, climate, and other inputs constant*, leads to a decrease in the rate of per capita state economic growth between periods *t-1* and *t* of one percentage point. Thus, $\hat{\alpha}_1$ measures the effect of changes in energy intensity net of changes in energy prices and other factors. We believe this net effect approximates the effect of changes in energy efficiency.

Although we control for energy prices, industrial composition, new capital, and climate in (5), it is still possible that we have omitted other factors that determine both energy intensity and GSP. This could lead to a biased estimate of $\hat{\alpha}_1$, although the direction of that bias is unknown. In addition to omitted variables bias, the estimation of (5) by OLS could lead to a biased $\hat{\alpha}_1$ if energy intensity and GSP are simultaneously determined. Implicit in the estimation of (5) by OLS is the assumption that the stochastic process that determines energy intensity in (4) is independent of the stochastic process that determines GSP in (5).[30] This may not be true. Unfortunately, we have no truly exogenous source of variation in energy intensity and so a two-stage least squares or instrumental variable estimation strategy is infeasible. Given the inability to correct for these two potential sources of bias, we believe $\hat{\alpha}_1$ reported below should be treated conservatively as an upperbound.

It is argued that most aggregate time series, like GSP, are nonstationary (Kennedy 1998). In an effort to correct for this potential problem, we estimate (5) using first

[30] This is akin to assuming the system represented by (4) and (5) is fully recursive (Greene 1993). More formally, we assume $\text{cov}[\Delta_{t-1} \ln EI, \varepsilon_t] = 0$ and the disturbances in (4) and (5) are uncorrelated.

differenced data.[31] Doing so frames the analysis in terms of changes in growth rates instead of changes in levels. It should be noted that this is a highly restrictive econometric specification of growth in the sense that it uses a relatively small fraction of the total variation in the data.[32] While this specification guards against biases that could arise from unobserved heterogeneity in the data, this protection comes at the cost of greatly restricting the variance of the explanatory variables used to identify their marginal effects. It is well known that other misspecifications, like random measurement error, are more problematic when relying on group estimators (Griliches and Mairesse 1995). We use lagged first differences in energy intensity because concurrent values of GSP and energy intensity are likely to be highly correlated for definitional reasons.[33] The effect of lagged energy intensity on GSP, though, has a more plausible causal interpretation.

B.3 Results

Table B.3 presents our baseline regression results of the effect of changes in the growth rate of industrial and commercial energy intensity on state economic growth. The coefficients on industrial and commercial energy intensity (–0.023 and –0.017) indicate that GSP growth rises as state economies become less energy intensive. These estimates tells us that a ten percent increase in the rate of growth in industrial energy intensity, for example, leads to a 0.23 percent decline in the rate of state economic growth. The remaining covariates in the model generally have signs and magnitudes consistent with the literature on state economic growth. One exception is the coefficient estimate on *New capital*. Investment is generally thought to be the cornerstone of economic growth, and so it is somewhat puzzling that *New capital* is statistically insignificant. This is at odds with the literature on economic growth in general, although the measurement of industrial

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[31] See Greene (1993). Diagnostic tests indicate that the first differenced GSP series is not significantly autocorrelated. We do, however, correct for heteroscedasticity between panels using the Huber-White sandwich estimator. The variable *New capital* is not first differenced since it is already measured as a flow.

[32] The use of first differenced data may alleviate some of the concerns about the endogeneity of energy intensity. While it seems likely that the level of energy intensity and GSP are simultaneously determined, it may be more plausible to argue that their growth rates are not.

[33] Consider the following regression: $Y=\beta E/Y+\varepsilon$. The estimated value of β will be positive so long as growth in energy consumption outpaces the growth in output, otherwise it will be negative. This is true by definition and so it is hard to give β a causal interpretation. This will also be the case in (5) since sectoral output, Y, is highly correlated with GSP.

capital is generally difficult and the particular measure used here is different from those employed in other studies of state economic growth.[34] Also, as noted above, the effect of any measurement error in this variable (which tends to bias the coefficient toward zero) will be exacerbated using first differences and state fixed effects. Note that the addition of new commercial buildings, a variable that is easier to quantify than industrial capital, has the expected sign and is of a substantial magnitude.

It is important to emphasize that the marginal effects of energy intensity estimated here hold prices, industrial mix, and new capital constant. Thus, the estimated effects are net of any influences these other variables might have on economic growth. In other words, the coefficients on energy intensity tell us what would happen to state economic growth if energy intensity were to change for reasons other than changes in prices, industrial mix, and investment in new capital and commercial buildings. One reason, of course, energy intensity could change is if there were technological advances that allowed energy to be used more efficiently. The hope is that these coefficients on energy intensity capture this effect alone. Still, energy intensity could change for other unidentified (and, therefore, uncontrolled) reasons and so these estimates should be thought of, conservatively, as upperbounds.

Although, at first glance, these coefficients appear small, their cumulative effects over time on the level of state GSP can be quite large. This is because growth is an exponential process. Table B.4 illustrates the predicted effect of energy intensity on state economic growth using data on GSP and energy intensity averaged across the 48 states in our analysis. The first three columns list the mean values of *Ind. EI*, *Com. EI*, and per capita GSP. The final column estimates what per capita income would have been had there been no change in energy intensity between 1977 and 1993.[35] Actual per capita GSP in 1995 was $21,138 ($1982). Had there been no change in energy intensity, the model predicts per capita GSP in 1995 would have been $20,575. Thus, we can conclude that the decline in industrial and commercial energy intensity between 1977-93 increased per capita income in 1995 by 2.74 percent, or $563 ($700 in 1998 dollars). Considering

[34] See, for example, Munnell (1990) and Holtz-Eakin (1993) who construct their own state series on capital accumulation.
[35] Because the data are first differenced and lagged one period we lose two years of data.

the size of the U.S. population, by these estimates, the decline in energy intensity made a significant contribution to aggregate welfare over this period.

The calculations in Table B.4 are based on the mean change in industrial and commercial energy intensity over all states for each year of the sample. Standard econometric theory tells us, however, that our ability to predict changes in GSP attributable to changes in energy intensity will become weaker as we move away from the mean of the data used to calculate $\hat{\alpha}_1$. That is, the precision of our forecast will diminish as we move toward the extremes of our data set (Greene 1993). Thus Table B.4, also presents 95 percent confidence intervals around the predicted effect of energy intensity on GSP.[36] Note that this interval widens as we deviate further from the mean value of *Ind. EI* and *Com. EI* (28.12 and 5.36). In 1995, the 95 percent confidence interval lies between $679 and $721 ($1998).

B.4 Results for California

The energy intensity coefficients estimated in (5) represent average effects over the 48 states in the analysis. It is entirely plausible that the effect of energy intensity on economic growth in California deviates from this average. Unfortunately, we do not have sufficient data to produce these coefficients separately for California. One approach, then, is simply to apply the energy intensity coefficients estimated for the entire sample to data from California.

The first three columns in Table B.5 list the mean values of *Ind. EI*, *Com. EI*, and per capita GSP for California. As in Table B.4, the fourth column estimates what per capita income would have been had there been no change in energy intensity between 1977 and 1993 assuming energy intensity has the same effect in California as it does on average in the other states in our sample. Actual per capita GSP in California in 1995 was $23,415 ($1982). Had there been no change in energy intensity, the model predicts per capita GSP in 1995 would have been $22,712. By this estimate, the decline in industrial and commercial energy intensity between 1977-93 increased per capita income in 1995 in California by 3.1 percent, or $704 ($875 in 1998 dollars). Since the change in

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[36] We approximate this interval as $\hat{y}_j \pm 2\left[\hat{\sigma}^2 X_j (X'X)^{-1} X_j'\right]$.

energy intensity in California deviates from the average change in the entire sample used to calculate $\hat{\alpha}_1$, we generate 95 percent confidence intervals around the predicted effect of energy intensity on GSP as we did above in Table B.4. These bounds are presented in columns 5 and 6. These estimates imply that the decline in energy intensity in California increased per capita income by between \$853 and \$898 in 1995 (\$1998).

A second approach is to group states with similar characteristics together and estimate the model separately for each group. The coefficient estimates then presumably reflect the unique circumstances of those states. We experiment with 3 different categorizations that divide the sample into quartiles based on industrial intensity (i.e., percentage of GSP accounted for by industrial output), industrial energy prices, and climate. We also divide states into those with no, weak, and strong building codes and by Department of Energy (DOE) region (10 regions).[37] The trouble with this approach, of course, is that by dividing the sample into groups our coefficient estimates are derived from substantially smaller samples and so are generally less precisely estimated. Also, it is possible that by grouping states in one dimension, we may also group them by some other unknown dimension which could have unpredictable effects on the coefficient estimates.

Table B.6 presents the industrial and commercial energy intensity coefficients for the group of states in which California falls for each of these 5 categorizations.[38] The only estimates that seem to tell a consistent story are those based on industrial intensity. We would expect that changes in industrial energy intensity would have less of an effect on GSP in states with relatively low industrial intensity. This is indeed what we see in the data. States in the first quartile of industrial intensity, like California, have a relatively small and imprecisely estimated coefficient on *Ind. EI* and relatively large coefficient on *Com. EI.* This is reversed in states in the fourth quartile of industrial intensity (not shown)—they have a relatively large coefficient on *Ind. EI* and relatively

[37] See Ortiz and Bernstein (1999) for a listing of states by type of building code.

[38] California is in the first (i.e., lowest) quartile of states by industrial intensity and climate and the fourth quartile of states by industrial energy prices. It is in DOE's West region and among states with strict building codes.

small coefficient on *Com. EI.* The other categorizations do not yield any discernable pattern in the coefficient estimates.

Table B.7 assumes that the coefficient estimates generated by states in the first quartile of industrial intensity are representative of the effect of industrial and commercial energy intensity on GSP in California. By these estimates, the decline in industrial and commercial energy intensity between 1977-93 increased per capita income in 1995 in California by 4.9 percent, or roughly $1,100 ($1363 in $1998). The 95 percent confidence interval for this estimate lies between $1,308 and $1,419 in 1995 ($1998).

B.5 Tables and Figures

Table B.1. U.S. and California Industrial and Commercial Energy Intensity (10^3 Btus/$): 1977-1995

	U.S.		California	
Year	Ind.	Com.	Ind.	Com.
1977	31.97	6.43	21.22	4.36
1978	30.10	6.26	19.12	4.11
1979	31.39	6.42	19.48	4.39
1980	31.78	6.61	18.65	4.64
1981	29.82	6.40	16.10	4.74
1982	28.56	6.32	14.37	4.30
1983	28.57	5.96	15.24	3.64
1984	27.67	5.87	15.69	3.50
1985	26.60	5.42	14.76	3.18
1986	26.14	4.93	13.60	2.79
1987	26.33	4.85	13.80	2.78
1988	26.60	4.99	12.77	2.75
1989	27.06	4.97	13.84	2.70
1990	27.12	4.82	14.44	2.69
1991	27.47	4.65	15.27	2.54
1992	27.98	4.29	15.90	2.43
1993	27.39	4.26	16.12	2.31
1994	26.08	4.15	15.73	2.22
1995	25.83	4.14	15.24	2.25

Notes: All figures in $1982.

Table B.2. The Determinants of Industrial and Commercial Energy Intensity

	Ind. EI		*Com. EI*	
	Coef.	Std. Err.	Coef.	Std. Err.

P^e	-0.585	0.087	-0.049	0.073
Manufacturing	0.325	0.046	—	—
Mining	0.042	0.021	—	—
New capital	-0.017	0.023	—	—
Building	—	—	-0.150	0.076
Climate	0.231	0.142	0.547	0.114

Notes: All variables are in logs. Regressions include state and time fixed effects. Standard errors are corrected for heteroscedasticity.

Table B.3. The Effect of Energy Intensity on Per Capita State Economic Growth: 1977-1995

	Coef.	Std. Err.	95% confidence interval		
Ind. EI	-0.023	0.007	-0.036	-	-0.009
Com. EI	-0.017	0.009	-0.035	-	0.000
Tran. EI	0.007	0.012	-0.017	-	0.031
Ind. P^e	-0.010	0.009	-0.028	-	0.008
Com. P^e	-0.029	0.009	-0.047	-	-0.011
Tran. P^e	0.016	0.023	-0.029	-	0.060
Manufacturing	-0.013	0.006	-0.026	-	0.000
Mining	0.012	0.004	0.005	-	0.019
New Capital	1.8E-06	2.1E-06	-2.4E-06	-	6.0E-06
Building	0.237	0.076	0.088	-	0.386
Climate	0.007	0.011	-0.014	-	0.028
Age 18-64	1.227	0.173	0.887	-	1.567
Bachelors	0.000	0.006	-0.011	-	0.012
Government	-0.395	0.049	-0.492	-	-0.298
Service	-0.642	0.073	-0.785	-	-0.498

Notes: All variables, except *New capital* are in logged first differenced form. See text for variable definitions. Regression controls for state and year fixed effects. Standard errors are corrected for heteroskedasticity across panels.

Table B.4. Predicted Effect of Industrial and Commercial Energy Intensity on State Per Capita GSP: 1979-1995

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual per capita *GSP*	Per capita GSP given no change in *Ind. EI* or *Com. EI*	Lower-bound effect	Upper-bound effect
1979	-0.065	-0.026	13,600	13,560	13,546	13,574
1980	0.040	0.016	12,910	12,813	12,805	12,822

1981	0.020	0.032	13,172	13,047	13,039	13,055
1982	-0.072	-0.034	13,243	13,106	13,091	13,122
1983	-0.044	-0.010	13,793	13,672	13,663	13,680
1984	-0.002	-0.062	14,940	14,764	14,749	14,779
1985	-0.041	-0.022	15,882	15,641	15,631	15,651
1986	-0.038	-0.081	16,968	16,644	16,620	16,668
1987	-0.047	-0.094	17,512	17,111	17,081	17,140
1988	-0.003	-0.012	18,013	17,571	17,567	17,575
1989	0.005	0.022	18,134	17,694	17,687	17,701
1990	0.019	-0.005	18,332	17,886	17,882	17,891
1991	0.010	-0.030	18,748	18,303	18,294	18,313
1992	0.015	-0.034	19,445	18,989	18,977	19,000
1993	0.016	-0.080	20,011	19,532	19,505	19,559
1994	-0.016	-0.010	20,937	20,428	20,422	20,433
1995	-0.051	-0.024	21,138	20,575	20,558	20,592

Notes: Estimates assume a constant marginal effect of *Ind. EI* of –0.023 and *Com. EI* of –0.017 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in $1982.

Table B.5. Predicted Effect of Industrial and Commercial Energy Intensity on Per Capita GSP: California, 1979-1995

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual per capita *GSP*	Per capita GSP given no change in *Ind. EI* or *Com. EI*	Lower-bound effect	Upper-bound effect
1979	-0.105	-0.060	16,040	15,979	15,949	16,008
1980	0.019	0.065	15,345	15,296	15,277	15,315
1981	-0.044	0.057	15,397	15,348	15,330	15,366
1982	-0.147	0.020	15,757	15,656	15,625	15,687
1983	-0.114	-0.096	16,500	16,312	16,275	16,348
1984	0.059	-0.166	17,950	17,661	17,611	17,710
1985	0.029	-0.040	19,246	18,891	18,877	18,905
1986	-0.061	-0.097	20,795	20,296	20,259	20,332
1987	-0.082	-0.129	21,696	21,074	21,022	21,126
1988	0.014	-0.003	22,255	21,616	21,611	21,620
1989	-0.077	-0.011	22,471	21,783	21,760	21,806
1990	0.080	-0.018	22,903	22,230	22,206	22,255
1991	0.042	-0.004	22,814	22,164	22,151	22,177
1992	0.056	-0.059	22,820	22,175	22,147	22,204
1993	0.041	-0.042	22,782	22,143	22,123	22,164
1994	0.014	-0.053	23,248	22,578	22,557	22,599
1995	-0.025	-0.041	23,415	22,711	22,692	22,729

Notes: Baseline estimates assume a constant marginal effect of *Ind. EI* of –0.023 and *Com. EI* of –0.017 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in $1982.

Table B.6. The Effect of Industrial and Commercial Energy Intensity on California's Rate of Economic Growth: Sensitivity Analysis

	Ind. EI		*Com. EI*	
Group	Coef.	Std. Err.	Coef.	Std. Err.
Baseline				
Low industrial intensity	-0.021	0.016	-0.045	0.019
High industrial energy prices	-0.007	0.011	-0.026	0.013
Mild climate	-0.049	0.020	0.018	0.025
Strict building codes	-0.006	0.021	-0.001	0.040
West DOE region	-0.036	0.010	-0.013	0.012

Notes: Regressions control for all covariates listed in Table B.3. See text for explanation of groupings. Standard errors are corrected for heteroscedasticity across panels.

Table B.7. Predicted Effect of Industrial and Commercial Energy Intensity on California Per Capita GSP: Alternative Coefficient Estimates.

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual per capita *GSP*	Per capita GSP given no change in *Ind. EI* or *Com. EI*	Lower-bound effect	Upper-bound effect
1979	-0.105	-0.060	16,040	15,954	15,876	16,031
1980	0.019	0.065	15,345	15,300	15,257	15,344
1981	-0.044	0.057	15,397	15,377	15,347	15,407
1982	-0.147	0.020	15,757	15,697	15,631	15,763
1983	-0.114	-0.096	16,500	16,315	16,219	16,410
1984	0.059	-0.166	17,950	17,588	17,497	17,680
1985	0.029	-0.040	19,246	18,794	18,770	18,817
1986	-0.061	-0.097	20,795	20,142	20,052	20,232
1987	-0.082	-0.129	21,696	20,845	20,717	20,974
1988	0.014	-0.003	22,255	21,379	21,371	21,387
1989	-0.077	-0.011	22,471	21,540	21,484	21,596
1990	0.080	-0.018	22,903	21,970	21,921	22,018
1991	0.042	-0.004	22,814	21,900	21,873	21,927
1992	0.056	-0.059	22,820	21,874	21,829	21,920
1993	0.041	-0.042	22,782	21,817	21,784	21,850
1994	0.014	-0.053	23,248	22,213	22,173	22,252
1995	-0.025	-0.041	23,415	22,319	22,274	22,363

Notes: Baseline estimates assume a constant marginal effect of *Ind. EI* of –0.022 and *Com. EI* of –0.045 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in $1982.

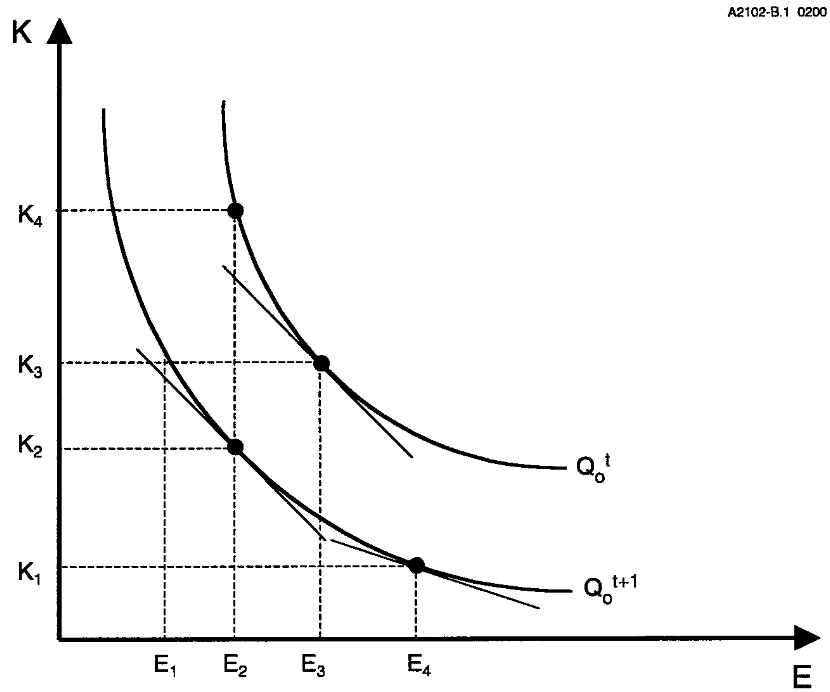

Figure B.1. Technical change.

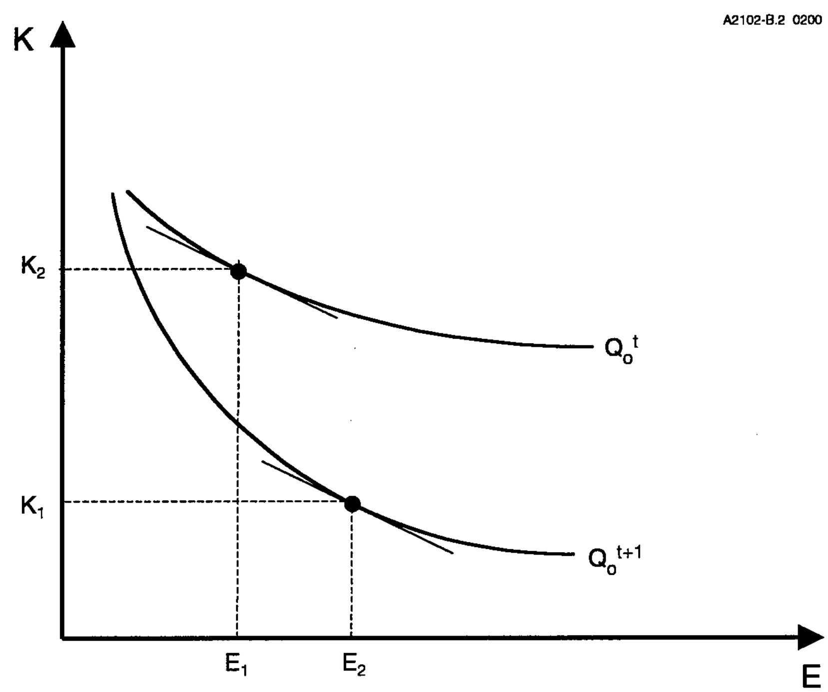

Figure B.2. Non-neutral technical change.

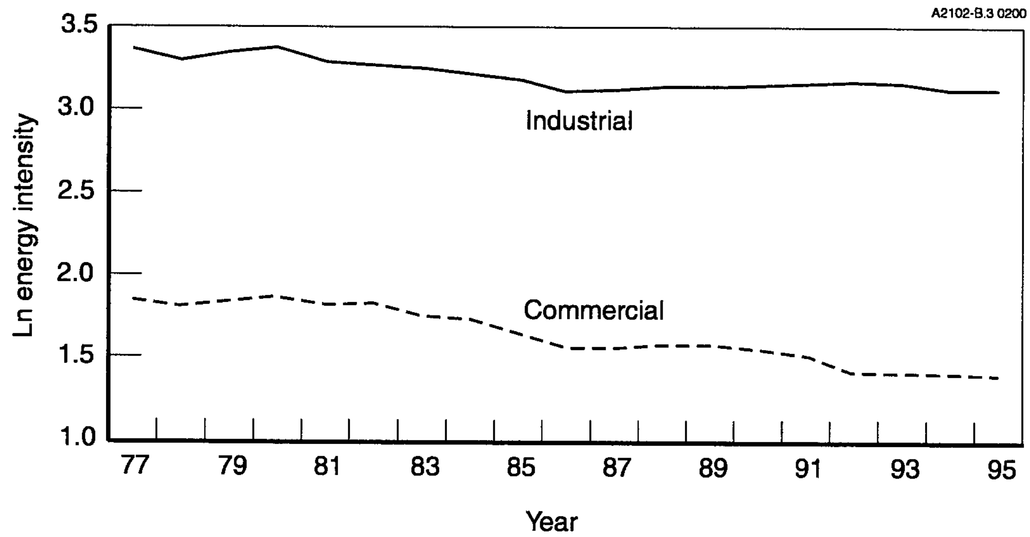

Figure B.3. Energy intensity: 1977-1995

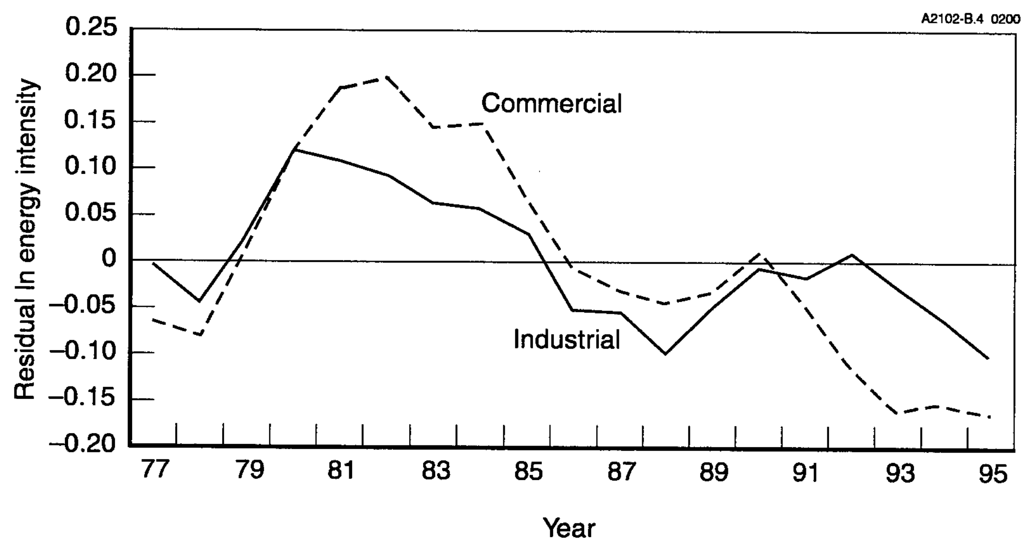

Figure B.4. Energy intensity residuals: 1977-1995

C Forecasting methodology: Calculating the value of energy intensity to the California economy

C.1 Past value

To estimate the value of improvements in energy intensity to the California economy, we start with the expression used in the regression (Eq. 5) from the Appendix B), rewritten as:

$$\Delta_t \ln \mathrm{GSP_t} = \alpha_t' + \Delta_{t-1} \ln \mathrm{EI_{ind}} \alpha_{ind} + \Delta_{t-1} \ln \mathrm{EI_{comm}} \alpha_{comm}$$

where $\mathrm{GSP_t}$ is the gross state product, α_t' is the growth rate of state product in the year t due to all causes except changes in energy intensity, $\mathrm{EI_{ind}}$ and $\mathrm{EI_{comm}}$ are the industrial and commercial energy intensities, respectively, and α_{ind} and α_{comm} are the coefficients relating changes in energy intensity to changes in the rate of growth of state product.

For the period 1977 to 1995, we have data on the gross state product and the industrial and commercial energy intensities. Using values of the coefficients α_{ind} and α_{comm} obtained from the regression analysis, we can calculate, α_t', the growth due to factors other than changes in energy intensity. We can then estimate what the state gross product would have been if energy intensity had not improved from 1977 through 1995, by writing

$$\Delta_t \ln \mathrm{GSP_t'} = \alpha_t'$$

where the estimate of what gross product would have been without energy intensity improvements depends on our estimates of the impact of energy intensity, as represented by the coefficients α_{ind} and α_{comm}.

The value of the changes in energy intensity that did occur, measured in terms of impacts on state gross product, are thus given in each year t by

$$\text{Value of changes energy intensity}_t = \mathrm{GSP_t} - \mathrm{GSP_t'}$$

This estimate depends on our estimates of the coefficients α_{ind} and α_{comm}. Since there is uncertainty in these estimates, we calculate a range of estimates for the value of changes in energy intensity corresponding to our range of estimates for the coefficients.

C.2 Future value

We can similarly estimate the value of improvements in energy intensity by making forecasts of future growth in gross state product and future trends in energy intensity. Forecasts of each of these factors are available from a variety of sources, but the one thing we know for certain about forecasts is that they are generally wrong. Rather than use a single forecast, we will thus use past trends to create an ensemble of forecasts and calculate the value of changes in energy intensity across this ensemble.[39]

To calculate an ensemble of future growth rates of gross state product due to factors other than changes in energy intensity, we estimate future values of α_t' from its past trends. This growth rate has waxed and waned between 1977 and 1995, with recessions in the early 1980s and 1990s, interspersed with periods of rapid growth. We calculate high, low, and medium estimates for α_t' of 3.25%, 2.23%, and 1.33% by calculating the average growth rates over the periods 1977 to 1987, 1977 to 1995, and 1986 to 1995.

Similarly, we calculate an ensemble of scenarios of future trends in energy intensity, as shown in Figure 3.2, by projecting the average rate of change over the 1986 to 1995, 1977 to 1995, and 1977 to 1987 periods, out into the future.

For each combination of forecasted energy intensity trends, state gross product due to factors other than changes in energy intensity, and estimates of the impacts of changes in energy intensity, we can then estimate the future value of the energy intensity using the same formula as we used to estimate the past value.

C.3 Benefits and costs of energy efficiency programs

We can use our estimates of the value of energy intensity to provide a rough estimate of whether or not the value of energy efficiency programs exceeds the costs of those programs. Most estimates of the value of energy efficiency programs take a bottom-up approach. In the spirit of this analysis, we take a top-down approach.

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[39] The American Heritage dictionary defines ensemble as a unit or group of complementary parts that contribute to a single effect. Our use of the term here is meant to signify that a single forecast is much less valuable than a range of scenarios employed towards a common purpose.

First, we use our estimates of the value of energy intensity to calculate the value of each unit of energy saved through improvements in energy intensity. For instance, using our best-estimate values of the coefficients α_{ind} and α_{comm} we find that on average from 1977 to 1995 improvements in energy intensity improved gross state product by $37,000 per GWh of energy saved. Next we compare these savings to the cost of the program to determine how much energy the program needs to save in order for its benefits to exceed its costs. From 1977 to 1995, the state spent roughly $4 billion on these programs, which means that the programs' benefit would exceed their cost if they save roughly 108,000 GWh of energy during that period. The CEC claims that these programs in fact saved 427,500 GWh of energy during this period. RAND has not made independent estimates of these savings. But these numbers suggest that if the programs saved at least 25 percent of what has been estimated, then their benefits exceed their costs. Discounting these costs using a 5 percent discount rate gives a slightly improved result for the programs -- they need only save 21 percent of the energy claimed in order for their benefits to exceed their costs. These estimates depend on a variety of assumptions, most notably that the value of improvements in the types of energy intensity addressed by the programs is roughly similar to the average value of energy intensity improvements across the California economy.

RAND

MR-1212.0-CEC

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